2. Site Evaluation for Reuse and Land Treatment

This section provides guidelines for land application site evaluations on the basis of environmental, management, and sociological factors. It is meant to be a general discussion of these factors, rather than an itemized list of materials and topics for permit applications. These lists can be found in Section 1. All sites have limitations, but with appropriate system design, many of these limitations can be overcome. It is incumbent upon the applicant to supply adequate justification to demonstrate feasibility of the proposed design, but DEQ works with wastewater reuse facilities through the permitting process to meet their needs in a reasonable way while protecting the waters of the state and public health and safety.

Land application site characteristics determine the potential for effective reuse of wastewater and its constituents. Although these characteristics also directly influence the potential for the transport of constituents from the site surface to beneficial users of ground water, land based reuse systems are to be evaluated as *treatment*, not disposal systems, the objective being to treat the wastewater to prevent problems related to ground and surface water pollution and nuisance situations. Sites should be evaluated, and systems designed, for sustainability for the long term, so that if and when site closure becomes necessary, land treatment sites may return to other uses involving negligible remedial activity. See Section 6.7 for further discussion of site closure.

The key site-specific features and characteristics to evaluate for land treatment include the following:

- Environmental factors
    - Climate
    - Soil
    - Topography
    - Geology and hydrogeology
- Crop Management
    - Crop selection
    - Crop management
    - Evapotranspiration
    - Crop nutrients
- Sociological factors and land use
    - Proximity to water supply wells and surface water bodies
    - Proximity to the public

Interaction between these factors and their resultant influences on the effectiveness of land application processes are discussed in the following sections.

> **Note:** The 2007 *Manual of Good Practice for Land Application of Food Processing Reuse Water* (California League of Food Processors), the 2001 Spray Irrigation Systems Operators Training Manual (North Carolina Department of Environmental Quality), and the 2005 Implementation Guidance for the Ground Water Quality Standards (Washington Department of Ecology), provided significant contributions to the text of this section.

2.1 Environmental Factors

Initial site evaluation is an important step in determining the potential an area might have for the treatment of wastewater. This general investigation can provide good background for further evaluation and prevent possible costly detailed site reviews. Environmental factors to evaluate include climate, soils, topography, geology and hydrogeology.

A discussion of the needs of the soil crop treatment system is also included in these guidelines and can be helpful in initial site evaluation.

2.1.1 Climate

Climate is the average weather of an area, including seasonal variations and weather extremes (such as prolonged periods of droughts or hurricanes) averaged over a period of at least 30 years (Miller, 2000).

Climate establishes many site characteristics because it

- affects the rates of physical, chemical and biological weathering processes over a large geographic area;
- influences soil properties;
- determines the types of vegetation or agricultural crops that may be grown;
- determines the rates of evaporation and evapotranspiration;
- determines the amount of precipitation that must be accounted for during site and system design; and
- determines the amount of storage that may be necessary for wastewater.

The two main factors that determine climate in a given area are temperature, with its seasonal variations, and the amount and distribution of precipitation.

2.1.1.1 *Temperature*

Temperature is important because the rates of assimilation and conversion of wastewater constituents by soil microbes are a function of temperature (Barker et al., 2000). The rate of microbial conversion of nitrogen compounds and the oxidation of organic wastes, in particular, *decreases* substantially with cool temperatures, making temperature a consideration in loading rate design. Plant assimilation of nutrients and organic matter *increases* with increasing temperature. Moreover, the length of the growing season and the occurrence of killing frosts and freezing conditions are temperature dependant, and temperature has a direct effect on evaporation and plant water use. See Section 4.4.6 for Idaho mean monthly temperature data (1971 – 2000).

2.1.1.2 *Precipitation*

The distribution and amount of precipitation is important to land application practices because of the potential implications for runoff, soil erosion, and leaching. For example, if an average annual rainfall of 24 inches is evenly distributed throughout the year (i.e., approximately 2 inches per month), less soil erosion and leaching will likely occur than would be the case if the same annual amount of rain fell at a rate of 4 inches per month over a six month rainy season.

Analysis of rainfall data should be conducted in terms of quantity and seasonal distribution. Types of precipitation data usually necessary for site suitability considerations for wastewater application and treatment include the following:

- total mean annual precipitation;
- mean monthly precipitation;
- peak storm event precipitation; and
- effects of snow on year round application systems.

Other climatic factors that may be considered in site selection include prevailing winds and wind velocity. The prevailing winds can have an important effect on site selection (Section 2.2.2).

See Section 4.1.1 for further discussion of precipitation with respect to crop needs and hydraulic loading. Figure 2-1 is a map of the average annual Idaho precipitation (USDA-NRCS, 1997). Section 4.4.4 has Idaho mean monthly precipitation data. Weather and climate data for a specific area can be obtained from the National Oceanic and Atmospheric Association (NOAA) (http://www.crh.noaa.gov). Other sources of data are discussed further in Section 4.1.1.2.2.

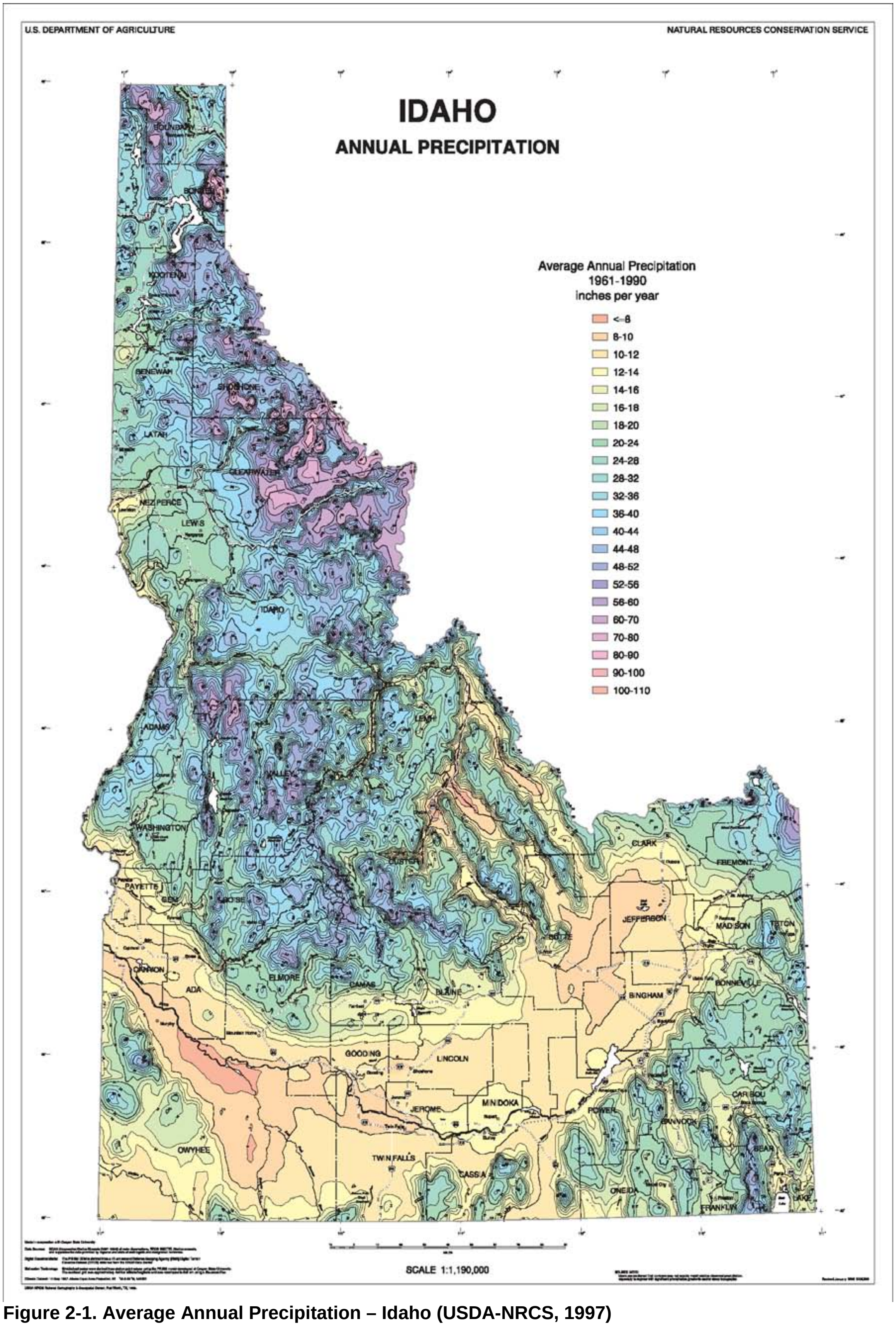

Figure 2-1. Average Annual Precipitation – Idaho (USDA-NRCS, 1997)

2.1.1.3 *Climate and Soil Forming Processes*

Climate is also considered by many soil scientists to be the most important factor in determining the properties of many soils. The main soil properties that correlate with climate are organic matter and nitrogen content, clay content, type of clay and iron minerals, the presence or absence of calcium carbonate ($CaCO_3$) and more soluble salts, and depth to the top of salt bearing horizons (Birkeland, 1984).

For example, the organic matter and nitrogen content of comparable soils generally tends to increase as one moves from a warmer to a cooler climate. This increase occurs because organic matter production (i.e., plant growth) exceeds destruction or microbial decomposition of organic matter at temperatures less than approximately 75°F (Brady and Weil, 2002). Organic matter and nitrogen also tend to accumulate in soils with increasing moisture.

Clay content tends to be highest in soils developed under conditions of high temperature and moisture because of increased weathering rates. Land application areas with high clay content require more intensive management because clayey soils are more difficult to work than coarser textured soils. Additionally, infiltration and permeability rates *decrease* as the content of clay increases.

Climate also influences the type of clay minerals present, with expansive (shrink-swell type) clays or *smectites*, such as montmorillonite, being more prevalent in drier environments. Non-expansive clays, such as *kaolinite*, are more common in warm, humid environments.

Agricultural soils containing smectites require special irrigation practices because swelling and dispersion of smectites may significantly decrease infiltration rates, particularly if the soils contain large amounts of sodium.

2.1.1.4 *Idaho Climate*

Idaho has a wide range of climates, which affect temperature, growing season and evapotranspiration. The climate in Idaho is generally suited to seasonal rather than year-round application of wastewater. Cold temperatures and freezing conditions limit the application of wastewater.

Temperatures range from an average of 53 degrees Fahrenheit (°F) in the Boise area to less than 44 °F in the mountains, including the higher mountain valleys. The growing season, where temperatures remain above 32 °F, can range from 135 to 165 days in the Boise area to less than 80 days in high mountain regions. See Section 4.1.1.1 and Figure 4-2 for further information. The evaporation rate from open water ranges from 40 inches in southern Idaho to 26 inches in some of the high valleys during the growing season.

The levels of precipitation in Idaho range from 6 inches in the southwest to nearly 80 inches in some higher mountain areas of the northern part of the state. Precipitation is generally highest when temperatures are at their lowest. In most areas Idaho precipitation is low. See Figure 2-1 for average annual precipitation in Idaho.

2.1.2 Soil

Soil is a porous mixture of organic material (highly decomposed plant and animal material (humus), mineral material (weathered rock, sand, silt and clay), water, and air. A medium-textured mineral soil contains around half soil solids (mineral and organic material) and around half *pore* space (air and water).

Soil is a three-dimensional body, resulting from the physical, chemical and biological weathering of bedrock or from the accumulation of materials weathered elsewhere and transported to a site. As soil develops on the landscape, distinct layers, called *soil horizons*, are formed.

Soil horizons differ from the overlying and underlying layers in some property, such as color, clay content, abundance of cracks, etc. A *soil profile* is a vertical slice of the soil showing the different horizons and their thickness (USDA, 1975).

Soil profiles with similar characteristics or properties are classified as a *soil series*. The characteristics of the soil series present at a proposed treatment site are a significant determining factor as to whether the site is suitable for the application of wastewater.

2.1.2.1 *Soils in Agriculture and Land Treatment*

Soils have four major roles to play in agricultural or other areas where land application of wastewaters occurs:

- The first role of soil is to function as a medium for plant growth. In this capacity, soils provide anchorage for vegetation, supply nutrients and water, and enable the exchange of gases between plant roots and the above-ground atmosphere.
- The second role of soil is to provide habitat for a multitude of organisms. In fact, soils harbor much of the genetic diversity of the Earth (Dubbin, 2001; Brady and Weil, 2002). A single handful of soil may contain billions of organisms that live and interact within a small space.
- The third role is that soils are important in the degradation and recycling of organic materials. Soils have the capacity to assimilate large quantities of organic waste and convert the nutrients in the waste to forms that may be utilized by plants and animals.
- Finally, soils play a major role in influencing the quality of water passing over or through them. Contaminated water passing through the soil may be cleansed of its impurities through a variety of soil processes, including microbial digestion and filtration. Conversely, clean water passing through a contaminated soil may itself become impacted.

2.1.2.2 *Soil Characterization*

Because of the important roles played by soil in land application, detailed descriptions of the physical and chemical characteristics of the soil within the entire rooting zone (the upper five feet) should be made prior to land application of wastewaters. Initial information on soil types, characteristics, and depths can often be obtained from the Soil Survey published by the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) and available online:

http://websoilsurvey.nrcs.usda.gov/app/

Soil Surveys are also available through the NRCS state and regional offices, USDA extension offices, Idaho soil conservation districts, and the Bureau of Land Management (BLM) district offices. Unpublished mapped areas may be available through local NRCS offices or the BLM district offices. For land that is under the jurisdiction of the USDA Forest Service, soils maps may be available through the local Forest Service office.

However, even if soil survey information is available, it should be supplemented with an investigation by a soil scientist to evaluate the suitability of the soil to adequately treat the wastewater. Hand-held soil auger boreholes and/or backhoe pits should be excavated and described.

Both physical and chemical soil characteristics should be described. Soil physical characteristics that should be described include available water capacity, slope, aspect, effective depth, texture of different soil horizons, horizon thickness and boundaries, type and amount of coarse fragments present, consistency; presence of rapidly draining materials; presence and depth of restrictive horizons, underlying bedrock or ground water, mottling, drainage class, roots, estimated organic matter content, color, structure, pH, infiltration rate, flooding potential, soil erodibility by wind and water, and soil temperature and moisture regimes.

Additionally, descriptions of soil chemical parameters may be needed. These include cation exchange capacity (CEC), type of clay, salinity, sodium adsorption ratio, initial nutrient status, coatings of oxides and sesquioxides (important in phosphorus and heavy metal sorption), and horizons with carbonate or salt accumulations may be needed.

Physical and chemical soil properties are described further in Sections 2.1.2.2.1 and 2.1.2.2.2 respectively. Table 2-1 provides a summary of several soil characteristics and rating criteria.

2.1.2.2.1 *Soil Physical Properties*

Certain physical properties including texture, available water holding capacity, effective depth, structure, infiltration, organic matter, soil color, drainage are discussed in detail below.

Texture

Texture is an important soil characteristic because it strongly influences the retention of water, nutrients, and pollutants:

- Coarsely-textured soils, such as sands and loamy sands, have large spaces (*macropores*) between their soil particles. Water and air pass through these macropores rapidly, so coarsely-textured soils are usually well-aerated and well-drained.
- However, wastewater often passes through these soils too quickly for significant treatment to occur.
- In addition, these soils may not hold sufficient water and nutrients to support a healthy vegetative cover. A poor vegetative cover can result in an increased potential for erosion and reduced uptake of water, nutrients, and pollutants.

Soil *texture* refers to the relative proportion of sand, silt and clay separates. Inorganic soil particles with diameters ranging from 2 to 0.05 millimeters (mm) are classified as sand; those with diameters ranging from 0.05 to 0.002 mm as silt; and those with diameters less than 0.002 mm as clay.

The major soil textural classes, as defined by the percentages of sand, silt and clay, are shown in Figure 2-2. In some soils, coarse fragment modifiers, such as stony, gravelly or cobbly are included as part of the textural class name. Fragments ranging in size from 2 to 75 mm along their greatest diameter are termed gravel, those ranging from 75 to 250 mm are called cobbles, and those more than 250 mm across are called stones or boulders.

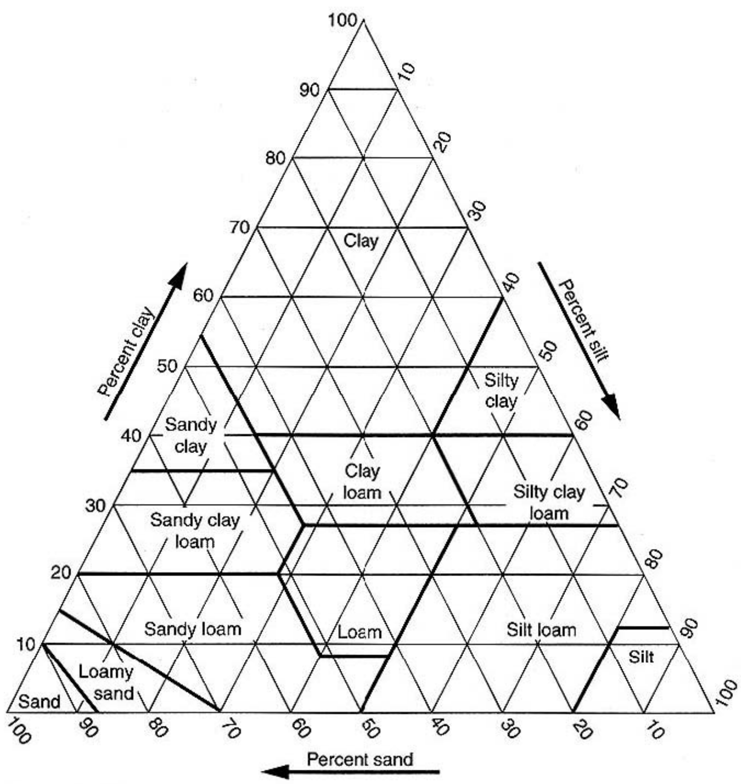

Figure 2-2. Textural triangle. The major soil textural classes are defined by the percentages of sand, silt and clay according to the heavy boundary lines shown (USDA, 2005).

Texture is one of the most important characteristics in determining fundamental soil properties, such as fertility, water-holding capacity, and susceptibility to erosion (Dubbin, 2001; Brady and Weil, 2002).

The typical influence of sand, silt and clay textures on some fundamental properties and behavior of soils are summarized in Table 2-1. Sites with surface textures of sandy loam, slit loam and loam have better tillage characteristics than soils with higher clay contents. In general, coarse-textured (sandy) soils can accept large volumes of water but do not retain much moisture. Fine-textured (clayey) soils can retain large volumes of water but do not drain well. Figure 2-2 shows that at a given soil water potential (Ψ), which units are in bars or atmospheres, the finer textured soils (clay) will have a higher volumetric water content than courser textured soils (sand).

Because of their small relative surface area, the sand and silt elements are far less reactive than clay. Sand and silt provide a relatively rigid framework for containing the clay and organic matter but by themselves function largely as a physical filter. On the other hand, the clays and organic elements of the soil matrix are extremely reactive, thus determining in large part the soil’s ability to treat wastewater. Soils that contain high volumes of coarse fragments have less reactive surface area for wastewater treatment.

Overall, deep, medium-textured (loamy) soils exhibit the best characteristic for wastewater irrigated systems. It should also be noted that limitations for land treatment of wastewaters may increase when the proportion of coarse fragments is high, decreasing both soil surface area for treatment of the applied waters and retention of water for crop growth.

Table 2-1. Influence of texture on soil properties and behavior (CLFP, 2007).

	Typical rating[a] associate with textural class		
Property and/or Behavior	Sand	Silt	Clay
Water-holding capacity	Low	Medium to high	High
Rate of drainage	High	Slow to medium	Very slow
Soil organic matter content	Low	Medium to high	High to medium
Organic matter decomposition	Rapid	Medium	Slow
Susceptibility to wind erosion	Moderate High if fine sand	High	Low
Susceptibility to water erosion	Low Moderate if fine sand	High	Low if aggregated High if not
Shrink-swell potential	Very low	Low	Moderate to very high, depending on clay mineralogy
Ease of tillage after rain	Good	Medium	Poor

Inherent fertility	Low	Medium to high	High
Potential for leaching	High	Medium	Low unless cracked
Susceptibility to pH change	High	Medium	Low

a Exceptions to these typical rating may be observed and are often related to soil structure or clay mineralogy.

Available Water Holding Capacity

Available water is defined as that portion of water in a soil that can be readily utilized by plant roots. The effective soil depth and texture have a significant impact on this soil property. Water in soils is held in pores, ranging in size from large cracks or *macropores* to tiny interlayer spaces or *micropores*. When all of the macropores and micropores in a soil are filled with water, the soil is said to be *saturated*.

Water is easily drained from a saturated soil because of gravitational forces. A soil is defined as being at *field capacity* when the soil is holding the maximum amount of water it can against the force of gravity. At this point, the water has drained from the macropores and is present only in micropores.

At field capacity, a plant will initially be able to extract water easily from the soil. However, soil water is held more tightly as the amount of water decreases and larger pores are drained. Eventually, plants are unable to extract sufficient water from the soil to survive, and the soil is said to be at its *permanent wilting point*.

Although clay-textured soils may contain large amounts of water at the permanent wilting point, this water is held so tightly that it is unavailable to plants. As a result, the amount of water held between field capacity and the permanent wilting point, the available water, is a more agronomically meaningful measurement than the total soil water content at field capacity.

The presence of organic matter increases the amount of available water directly, because of its greater water supplying ability, and indirectly, through beneficial effects on soil structure and total pore space. The variation in water content with field capacity (Ψ ranging from -0.1 to -0.3), available water, permanent wilting point ($\Psi =$ -15), and unavailable water ($\Psi <$ -15) given differing soil textures is illustrated in Figure 2-3.

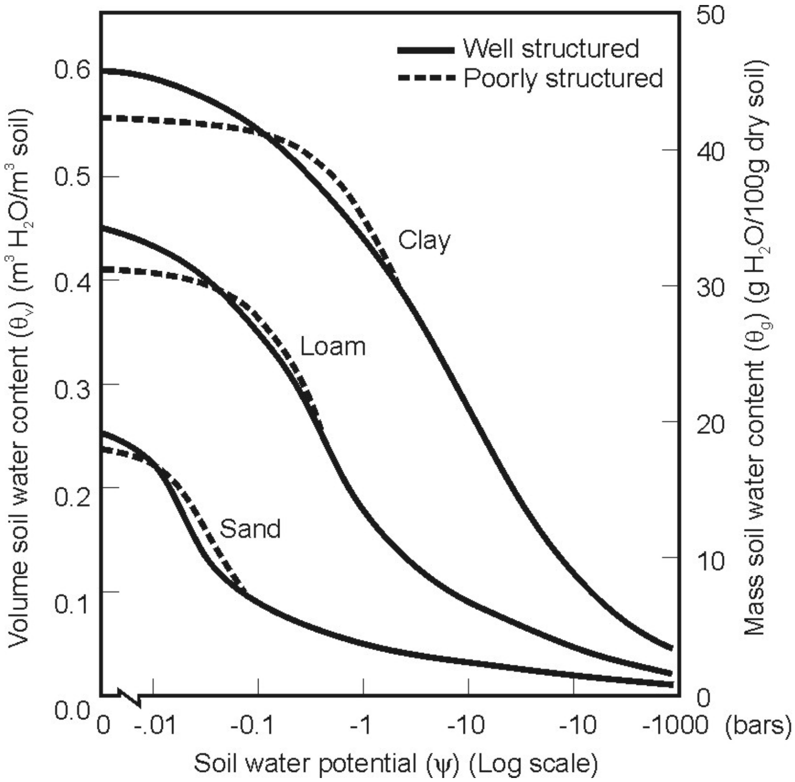

Figure 2-3. General relationship between soil water characteristics and soil texture.

Ranges in the available water holding capacity for different soil textures are summarized in Table 2-2 (Ashley et al. 1997). Additional information concerning the water holding capacities of soils can be found in Section 4.4.9.

Table 2-2. Available water holding capacity for different soil types (Ashley et al. 1997).

Soil Texture Class	Water Holding Capacity (in/in)	Water Holding Capacity (in/ft)
Sand	0.04	0.43
Loamy sand	0.08	0.94
Sandy loam	0.14	1.67
Sandy clay loam	0.14	1.67
Loam	0.17	2.10
Silt loam	0.20	2.44
Silt	0.18	2.12
Clay loam	0.16 – 0.18	2.0 – 2.16
Silty clay loam	0.18	2.16
Silty clay	0.17	2.04
Clay	0.16	1.94

Source of Data: R.E. McDole, G.M. McMaster, and D.C. Larson. 1974. Available Water-Holding Capacities of Soils in Southern Idaho. CIS 236. University of Idaho Cooperative Extension System and Agricultural Experiment Station.

Effective Depth

Effective depth refers to the depth of soil to seasonal ground water and/or a restrictive soil horizon that limits rooting depth. Adequate soil depth is important for root development, retention of wastewater constituents on soil particles, and microbial degradation of wastewater constituents. Most plants, both annuals and perennials, have the bulk of their roots in the upper 10 to 12 inches of the soil as long as adequate moisture is available.

Perennial plants, such as alfalfa and trees, have some roots that are capable of growing to depths greater than nine feet and are able to absorb a considerable portion of their moisture requirements from the subsoil (see Section 2.2.4.3.1 for further discussion of crop rooting depths). Retention of wastewater components is a function of their residence time in the soil and the degree of contact with soil particles. For land application sites, a soil depth of two feet or greater is generally adequate for wastewater treatment (Pettygrove and Asano, 1985; EPA, 2006, Crites et al., 2000). The ranking of soil depth both to bedrock and ground water as it affects site suitability is shown in Table 2-5.

Soil Structure

Soil structure is one of the principle factors that influences the rate of water movement. Soil structure refers to the arrangement of individual soil particles (sand, silt, and clay) into more complex aggregates or “peds”. These peds can be separated from each other along natural planes, zones or surfaces of weakness into distinct units.

Ped units may be granular, blocky, subangular blocky, columnar, prismatic, or platy. Soils that do not form structural units, such as very sandy soils, are considered structureless. Soils that don't naturally separate into structural units, such as very sticky clayey soils, are considered to have massive structure.

Soil structure affects water movement, both into and through the soil. Because water moves primarily between peds, soil structure can modify the influence of soil texture on water movement. Well-structured fine and coarse textured soils can be suitable for wastewater land treatment (Crites et al., 2000).

Water movement in finely-textured soils can be very slow, but clayey soils with well-developed blocky and subangular blocky structure can transmit reasonably large volumes of water between peds, even though these soils are finely-textured. In finely-textured soils with massive structure, (the clay is so sticky that individual peds do not form); water movement can be expected to be slow and restricted. Water movement can also be slow in soils with some platy, prismatic, or columnar structure.

Unlike texture, structure can be easily altered by management practices. Additions of organic matter can improve soil structure by acting as a binding agent for soil particles. Unfortunately, management practices often damage soil structure. If finely-textured soils are traveled with heavy equipment, tilled, or otherwise worked when wet, soil aggregates are destroyed and macropores disappear, resulting in *soil compaction*. In this condition, water and air cannot move through the soil. Even after the soil dries, structure remains destroyed. It is very important to keep heavy equipment off of land application fields when wet to avoid compacting the soil.

Infiltration

The process by which water enters the soil pore spaces and becomes soil water is termed infiltration. The rate at which water enters the soil surface is termed the infiltration rate (I), and is calculated using Equation 2-1:

$$I = \frac{Q}{A * t}$$

Equation 2-1. Infiltration rate.

Where Q is the volume of water (ft^3) infiltrating the soil, A is the soil surface area (ft^2) exposed to infiltration, and t is time in seconds (s). The units of infiltration are generally converted to inches per hour (in/hr). The infiltration rate is not constant with time, and generally decreases during an irrigation or rainfall event (Brady and Weil, 2002). If the soil is dry at the onset of infiltration, all of the macropores open to the surface will be available to conduct water into the soil.

In soils with expansive clays, the initial rate of infiltration may be quite high as water enters the network of shrinkage cracks formed during periods of drying or desiccation. As infiltration continues, many macropores become filled with water and the shrinkage cracks swell shut. Therefore, the infiltration rate declines sharply initially, and then begins to level off, remaining fairly constant thereafter and is often called the effective saturated conductivity of the soil (Crites et al. 2000).

Once the water has infiltrated the soil, the water moves downward into the soil profile by the process of percolation, or vertical permeability. The vertical permeability is often referred to as the vertical hydraulic conductivity (K_v) of the soil (Crites, et al. 2000).

Both saturated and unsaturated flow are involved in the percolation of water through the soil. Saturated flow occurs when the soil pores are completely filled (or saturated) with water, and unsaturated flow when the larger pores are filled with air, leaving only the smaller pores to hold and transmit water. As a result, macropores account for most of the water movement during saturated flow and micropores for movement during unsaturated flow.

Thus, coarse-textured sandy soils have higher saturated permeability than fine-textured soils, because they typically have more macropore space. Medium-textured soils, such as loam or silt loam, tend to have moderate to slow saturated permeability.

Infiltration and Land Treatment

Sites with soils that have either too rapid or too slow a permeability have lower wastewater treatment potential. Soils with rapid permeability can allow wastes to travel through the root zone without adequate treatment. Those that have slow permeability need more intensive management to avoid runoff, erosion, and hydraulic overloading.

The influence of texture on soil permeability is summarized in Table 2-3. For slow rate systems, typical soil permeabilities range from 0.05 to 2.0 in/hr (moderately slow to moderately rapid). These permeabilies generally correspond to soil textural classes from clay loams to sandy loams (EPA, 2006). Recommended permeabilities range from 0.2 – 6.0 in/hr (Crites et al., 2000; EPA, 2006). The ranking of permeability rates as they affect site suitability is shown in Table 2-5.

Table 2-3. Influence of texture on soil permeability (CLFP, 2007).

Soil Texture	Permeability (in/hr)
Coarse-textured soils—sandy soils	Moderately rapid: 2.0 to 6.0 Rapid: 6.0 to 20 Very rapid: > 20
Medium-textured soils—loamy soils	Slow: 0.06 to 0.20 Moderately slow: 0.2 to 0.6 Moderate 0.6 to 2.0
Fine textured soils—clayey soils	Very soil: < 0.06 Slow: 0.06 to 0.20

The conversion of soil permeability rates in the USDA Soil Survey to recommended design percolation rates (here calculated as the planned hydraulic load to be applied per year) is shown in Figure 2-4 (Crites, et al., 2000).

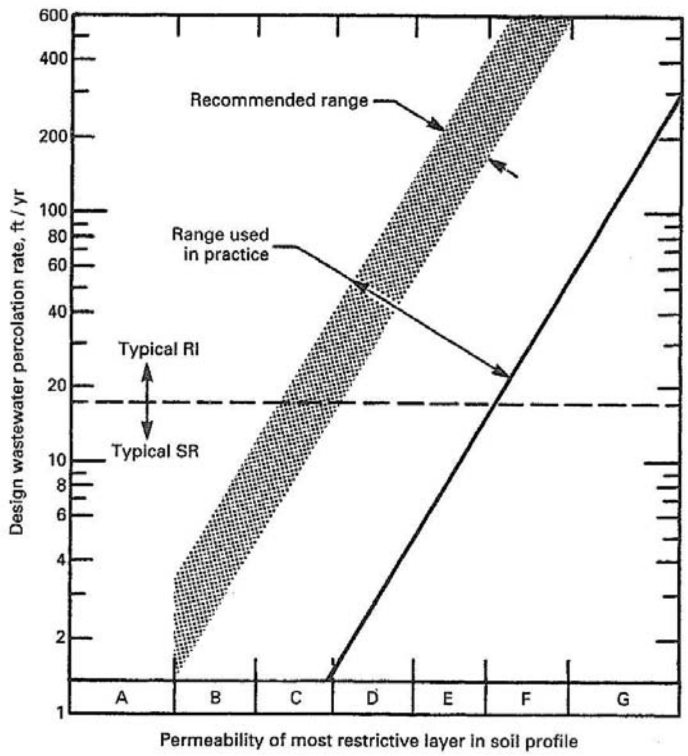

Figure 2-4. Design percolation rate vs. NRCS soil permeability classifications for slow rate and rapid infiltration land treatment (EPA, 1981).

Note: The zones A through G in Figure 2-4 refer to clearwater permeability for the most restrictive layer in the soil profile (K_v = in/h): A = very slow, <0.06; B = slow, 0.06 – 0.2; C = moderately slow, 0.2 – 0.6; D = moderate, 0.6 – 2.0; E = moderately rapid, 2.0 – 6.0; F = rapid, 6.0 - 20; G = very rapid, >20. (Crites, et al., 2000)

Infiltration Rate Testing

For proposed site, or if irrigation methods or application rates used on a site will be changing for the application of wastewater, infiltration rate testing may be warranted. This would be especially true for sites that could be prone to runoff, erosion, or extended ponding. Infiltration rate testing should also be performed if center pivot or linear move sprinklers are contemplated because of their very high instantaneous application rates. Infiltration tests can be performed using cylinder infiltrometers, basin infiltration tests, or other means described in EPA (2006). These tests can be a part of the site soils investigation described previously. The use of data from infiltration tests for system design is discussed in EPA (2006) and Crites et al. (2000).

Irrigation systems should be designed to deliver water at a rate that is less than the infiltration rate of the soil to minimize runoff or excessive percolation. Runoff and erosion may present problems if the soil infiltration rate is low, the land is relatively steep, and/or too much water is applied in one place. Water may be lost to deep percolation or runoff because of uneven distribution of water. Uneven distribution and excessive percolation of water may also result in crop death and yield losses in excessively saturated portions of the field.

Soil Organic Matter

Soil organic matter (humus) is composed of decomposing plant and animals and waste materials produced by soil microorganisms. The organic matter content of most mineral soils is generally less than five percent. However, organic matter serves several important functions in soil/plant treatment systems:

- Organic matter promotes soil structure formation in finer-textured soils. Good soil structure aids water movement in soil by increasing the pore space.
- In sandy soils, organic matter helps fill larger pores and increases the soil's ability to hold water, nutrients, and pollutants, thus increasing its treatment potential.
- Organic matter is a food source for soil microorganisms. Microbial activity, in turn, produces waste products that promote soil structure formation.
- Organic matter contains several plant nutrients, particularly nitrogen, phosphorus, and sulfur. As organic matter decays, these nutrients become available for use by plants and microorganisms.
- Organic matter has a high negative charge, which increases a soil's ability to retain water, nutrients, and pollutants.

Soil Color

Soil color is an indicator characteristic that is used to predict soil/water relationships in a soil profile. Soil color is an extremely useful tool when evaluating a site for suitability as a waste treatment system.

Soils that are well drained and do not have a seasonal high water table for a significant time during the year typically have rather bright colors due to oxidized or ferric iron (Fe^{+3}). Ferric iron imparts a reddish/orange color to the soil. When soil drainage is impeded, and the soil is saturated, the ferric iron contained in the soil is chemically reduced to ferrous iron (Fe^{+2}). Ferrous iron is soluble in water and as the water table recedes, this soluble iron is removed, leaving behind soil that is gray in color.

As the water table rises and falls, a characteristic pattern called *mottling* usually develops. Mottled soils generally contain bright orange and red areas mixed with light gray areas. These mottle patterns are impressed upon the original background, or matrix color, of the soil. The presence or absence of gray mottles or color in a soil is an indication of the wetness or aeration status of the soil:

The presence of light grayish mottles usually indicates a high water table or poorly drained soil. The depth to gray colors can be used to define the drainage class of a soil and indicate the depth of the seasonal high water table.

Soil color is determined by using an international color standard, the *Munsell* system. This standard was developed to describe colors and to avoid confusion that can arise by describing a color as simply red or yellow. The Munsell system uses three components of color to describe coloration within a soil: hue, value, and chroma:

- *Hue* is the dominant spectral color (red, yellow, etc.)
- *Value* describes the degree or darkness or lightness.
- *Chroma* refers to the purity or strength of the color.

A moist soil sample is compared to the color chips in a Munsell color book to identify the most appropriate match.

Soil Drainage

Soil *drainage* or *wetness* refers to the depth of the water table and to the period of time a particular part of the soil profile is saturated. A soil may be classified as *well drained, moderately well drained, somewhat poorly drained, poorly drained,* or *very poorly drained.*

Poorly drained soils have a water table at or within 12 inches of the soil surface for most of the year. Well drained soils have a water table depth of 60 inches or more during much of the year. The drainage class of a soil can usually be determined by observing both the color patterns of the soil profile and the soil's relative position on the landscape.

Poorly drained and very poorly drained soils are not generally considered suitable for the land application of wastewater for several reasons:

- wet soils do not provide adequate treatment capacity, and waste constituents may move directly to ground water
- seasonally wet soils may limit the type of plants that can be grown on the site and can impact the quality of the vegetative cover
- wet soils are subject to compaction by equipment traffic that destroys soil structure and reduces the infiltrative capacity of a site

The drainage class of a soil refers to water table depth, not permeability. Consequently, even though a soil might be coarsely-textured and relatively easily drained, a high water table due to landscape position can render the soil poorly drained. If an outlet or a drainage system is provided for soil water, then this poorly drained sandy soil may be modified. However, installing any type of drainageway or drainage system at a land application site is not recommended, since it could be a violation of the system’s permit conditions. The ranking of minimum depth to ground water as it affects site suitability is shown in Table 2-5. Depths to ground water of less that 4 feet may render a site poorly suited for land treatment.

2.1.2.2.2 *Soil Chemical Characteristics*

Wastewaters often contain nutrients and/or organic matter that can improve soil chemical, physical or biological properties of agricultural land. In fact, soil has a tremendous buffering capacity for receiving wastewater compared to air and water and may serve as the best choice for management of wastewaters with the least impact on the environment. However, there are several soil chemical characteristics that may need to be monitored periodically during land application to ensure that soil quality is not degraded, and that damage and/or toxicity to crops is prevented. These characteristics include:

- pH;
- Cation exchange capacity;
- Salinity; and
- Micronutrient and macronutrient concentrations.

The potential impact of land application of wastewaters on these soil characteristics are discussed in the following sections. The recommended frequency of monitoring for these parameters is discussed in more detail in Section 7.4. Sections 2.5.1 and 2.5.2 have tables of typical soil chemistry values for Idaho soils with low to high ratings dependant upon the agronomic needs of the crop.

Soil pH

The pH scale ranges from 0 (most acidic) to 14 (least acidic), and is logarithmic, meaning that each unit change in pH represents a ten-fold increase in acidity or alkalinity. Of all soil chemical characteristics, pH is the most important and influences diverse properties including nutrient availability, functioning of microorganisms and fate and transport of many contaminants. Table 2-4 gives summary interpretation of soil pH levels with respect to land treatment and crop growth (EPA, 1981).

Typically, a soil pH between 5.5 and 7 is optimal for nutrient availability to plants. The ability of a soil to resist changes in pH as a result of land application of wastewaters or other activities is termed its buffering capacity. The buffering capacity of a given soil increases with increasing organic matter, calcium carbonate content and cation exchange capacity.

Decreasing soil pH directly increases the solubility of manganese, zinc, copper, and iron, thereby increasing the availability of these nutrients. At pH values less than 5.5, toxic levels of manganese, zinc, or aluminum (a non-nutrient element common in soils) may be released. On the other hand, the availability of nitrogen, potassium, calcium, magnesium, and sulfur tends to decrease with decreasing pH.

Soils with pH less than five often contain soluble aluminum in concentrations that are toxic to plants, and show deficiencies of calcium, magnesium and molybdenum. Conversely, plants that require large amounts of iron, such as azaleas and rhododendrons, prefer acidic soil environments in which iron is most available.

The activity of microorganisms is also reduced in acidic soils, resulting in a reduction in the rate of nitrogen and phosphorus mineralization. The decreased rate of microbial activity also adversely affects soil structure, because the production of organic materials required for the formation of stable aggregates is insufficient. Heavy metals are less mobile in soils within a pH range of 5.6 to 7.9 and generally mobilize in soils with a pH value of 5.6 and below.

Soils with pH greater than nine generally contain sodium at concentrations high enough to be detrimental to soil structure (Brady and Weil, 2002; Dubbin, 2001). Additionally, plants grown in high pH soils may exhibit micronutrient deficiencies.

Phosphorus and boron availability decreases at both very low and very high pH, with maximum availability in the range of 5.5 to 7.0. Outside of this pH range, phosphorus and boron tend to form insoluble compounds with other elements, such as aluminum, iron, manganese, and calcium. These reactions bind phosphorus much more strongly than boron, with the result that available boron can be readily leached from soils.

Soil pH can be altered relatively easily with amendments. A typical soil amendment used to raise the pH is calcium carbonate (limestone), although many other possibilities exist. Increasing soil pH, however, is not the primary reason for *liming*. As just mentioned, aluminum and manganese are toxic to plants at relatively low concentrations in the soil solution. Low pH is an indicator that aluminum and manganese toxicity is likely. Liming decreases the solubility of aluminum, manganese, and iron (as well as zinc and copper), causing them to precipitate as relatively insoluble silicate clays, oxides and hydroxides.

Figure 2-5 shows the relationship between pH and nutrient availability.

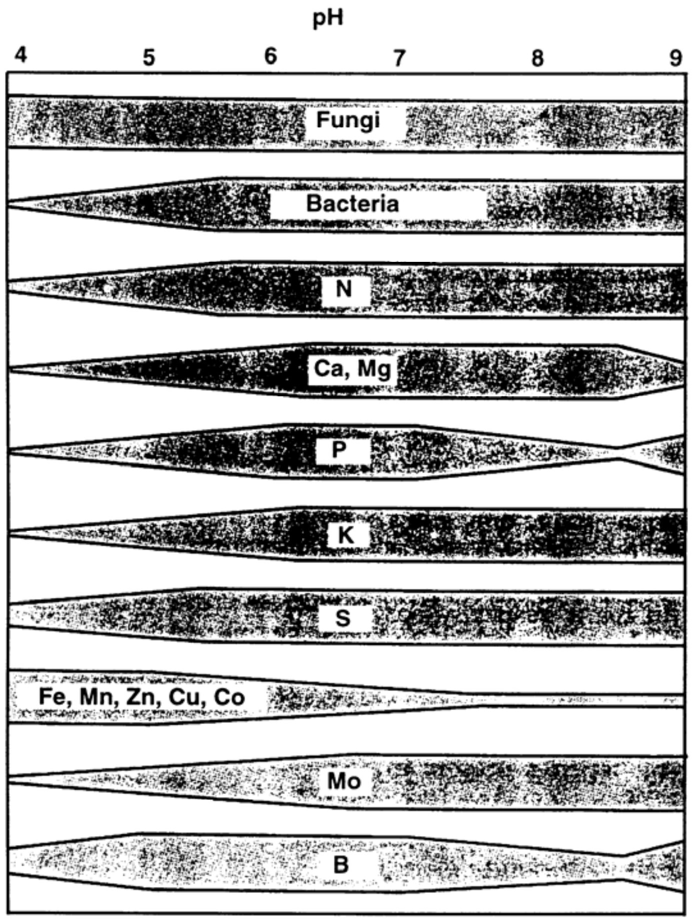

Figure 2-5. Relationships between pH on the one hand and the activity of microorganisms and nutrient availability on the other. The wide portions of the band indicate the zones of greatest microbial activity and the most ready availability of nutrients (Brady 1990)

Depending on the source, lime also supplies significant amounts of calcium and magnesium. Indirect effects of liming include increased availability of phosphorus, molybdenum and boron, the creation of more favorable conditions for microbiological processes such as nitrogen fixation and nitrification, and, in some cases, improved soil structure. By increasing soil pH, liming also improves the effectiveness of several herbicides.

Since lime applications decrease availability of zinc, iron, manganese, and copper, excessive lime applications can cause deficiencies of these elements. Heavy applications of lime have also caused decreased uptake of boron in some cases.

Table 2-4. Interpretation of Soil Chemical Tests (EPA, 1981)

Test Results	Interpretation
pH (Saturated Soil Paste)	
< 4.2	Too acid for most crops to do well
4.2 – 5.5	Suitable for acid-tolerant crops and forest systems
5.5 – 8.4	Suitable for most crops
> 8.4	Too alkaline for most crops: indicates a possible sodium problem
CEC (meq/100g)	
1 – 10	Sandy soils (limited adsorption)
12 – 20	Silty loam (moderate adsorption)
> 20	Clay and organic soils (high adsorption
Exchangeable Cations (% of CEC)	
Sodium	5
Potassium	60 -70
Calcium	5 – 10
Magnesium	10 – 20
ESP (% of CEC)	
< 5	Satisfactory
< 10	Reduced permeability in fine-textured soils
< 20	Reduced permeability in coarse-textured soils
EC_e (mmhos/cm at 25% of Saturation Extract)	
< 2	No salinity problems
2 – 4	Restricts growth of very salt-sensitive crops
4 – 8	Restricts growth of many crops
8 – 16	Restricts growth of all but salt-tolerant crops
>16	Only a few very salt-tolerant crops make satisfactory yields

Cation Exchange Capacity

The *Cation Exchange Capacity* (CEC) of a soil is a measure of the total of exchangeable cations (cationic charge) that may be adsorbed onto soil exchange sites, and therefore, represents an important measure of the nutrient holding capacity of a soil. The CEC is primarily due to the clay minerals present and organic matter content. The contribution of organic matter to CEC, on a weight basis, is approximately four times as much as that from the clay fraction (Dubbin, 2001). Typically, the highest CEC and fertility occur in clayey soils high in organic matter.

The CEC is expressed in terms of centimoles of positive charge adsorbed per kilogram of soil (cmol+/kg) which is equivalent to the more common units of milliequivalents of charge per 100 g of soil (meq/100g). The CEC of most soils typically ranges from approximately 3 to 50 cmol+/kg, and tends to increase with increasing pH (Brady and Weil, 2002).

At pH values <6.0, the CEC is generally lower. The CEC is typically measured at a pH of 7.0 or above to evaluate the maximum retentive capacity. The CEC of the soil is important in land application of wastewaters because leaching of cations from the applied water is more likely to occur in soils with low CEC (<5 cmolc/kg). In contrast, leaching of cations is reduced in soils with high CEC (>10 cmolc/kg). Table 2-4 provides interpretation of soil CEC levels and other chemical tests with respect to crop growth and land treatment (EPA, 1981)

Salinity and Sodium

Characterizing initial site soil salinity status is critical in evaluation of a potential land treatment site. Descriptions of constituents and their measurement are provided here. Discussion of soil salinity and sodium influences with respect to site loading and leaching requirement for salinity control and long-term sustainability is found in Sections 4.2.2.5 and 4.4.7.

Soluble salts are generally composed primarily of calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), and sulfate (SO_4^{-2}). Sodium is the most problematic of all the ions released by soluble salts. As discussed in Section 4.2.2.5.3, sodium disperses clay and organic matter, thereby degrading soil structure and reducing macropore space.

Soils high in sodium, therefore, are poorly aerated and have reduced permeability to water. Soluble salts alter osmotic forces in soils and impede the uptake of water by plants. Deleterious effects of salts on plants are also caused by toxic concentrations of sodium and chloride. Fruit crops are particularly susceptible to high concentrations of these elements. Additionally, the high pH caused by excess sodium may result in micronutrient deficiencies.

Measurement of Salinity and Sodium

An indirect measure of soluble salt content in soils can be obtained by measuring the electrical conductivity (EC) of the saturation paste extract of the soil water, designated as EC_e. An EC_e greater than 4 decisiemens per meter (dS/m), or millimhos per centimeter (mmhos/cm), indicates a saline soil, and an EC_e of 2 to 4 dS/m indicates moderately high soil salinity. The threshold for yield effects for the most sensitive crops begins at about 1 dS/m. The EC_e of soil subject to land application of wastewaters should be checked as part of the soil monitoring program to ensure that potentially harmful and/or toxic concentrations of soluble salts do not accumulate.

Where a paste-extract test is used, the exchangeable sodium percentage (ESP) and the Soil Absorption Ratio (SAR), two measurements of the sodium content in soils, should also be monitored. The ESP indicates the extent to which the CEC of the soil is occupied by sodium; the SAR provides information on the comparative amounts of sodium, calcium and magnesium in soil solutions. Soils with an ESP greater than 15 are classified as sodic soils. The percent of the CEC occupied by different cations, such as Ca, Mg, K, and Na, is also important, and is similar in concept to ESP. Table 2-4 provides interpretation of soil ESP and salinity (EC_e) levels with respect to crop growth and land treatment (EPA, 1981). Table 2-4 also provides percent ranges of various cations occupying exchange sites reflecting suitable levels with respect to crop growth and land treatment.

Geophysical Mapping of Site Soil Salinity

Discreet soil samples represent relatively very small volumes of soil from a site. Characterizing spatial salinity trends across a site using discrete soil samples is excessively expensive. Geophysical mapping using electromagnetic (EM) equipment can be cost effective for soil conductivity mapping. Using either a backpack or small trailer mounted unit, the site can be traversed to take hundreds of measurement points with a unit that measures electrical current eddies in the soil induced by an above-ground EM source.

Measurement locations are recorded on the fly with a geographical positioning system (GPS) unit. Depending upon the dimensions of the inductive equipment, the results can provide an indication of soil salinity up to 15 feet deep. The EM results should be calibrated with results from discreet soil samples at a few select locations. EM surveys are useful for background surveys of sites where salinity will be a particular concern and for long term (5 or 10 year interval) checking of trends (CLFP, 2007).

Soil Macronutrient and Micronutrient Concentrations

Concentrations of macronutrients and micronutrients should be monitored in soils irrigated with wastewaters. The purpose of this monitoring is to ensure that hazardous, or potentially toxic, levels of nutrients do not accumulate. Additionally, application of excess nitrogen can result in leaching of nitrate to ground water. Soil macronutrients and micronutrients are discussed further in Section 2.2.4.1. The recommended frequency of monitoring for these nutrients will vary depending on the characteristics of the soils and the chemistry of the wastewaters being applied. Soil and wastewater monitoring are discussed in Sections 7.4 and 7.5 respectively.

2.1.2.2.3 *Summary Site Characteristic Rating Criteria*

Table 2-5 gives ratings of certain site and soil properties for the potential suitability of a wastewater land treatment site (Taylor, 1981; EPA, 2006). Individual ratings are summed to determine whether a site is suitable for wastewater land treatment. Many site limitations can be overcome with appropriate system design, operation, and management. Other limitations may not be possible or economically feasible to overcome. In such cases, other sites should be considered.

Table 2-5. Rating Factors for Slow Rate System Site Selection (Taylor, 1981)

Characteristic	Agriculture	Forest
Soil Depth (feet)[1]		
1 – 2	E[2]	E
2 – 5	3	3
5 – 10	8	8
> 10	9	9
Minimum Depth to Ground Water (feet)		
> 4	0	0
4 – 10	4	4
> 10	6	6
Permeability (in/hr)[3]		
< 0.06	1	1
0.06 – 0.2	3	3
0.2 – 0.6	5	5
0.6 – 2.0	8	8
> 2.0	8	8
Grade (%)		
0 – 5	8	8
5 – 10	6	8
10 – 15	4	6
15 – 20	0	5
20 – 30	0	4
30 – 35	E	2
> 35	E	0
Existing or Planned Land Use		
Industrial	0	0
High Density Residential/Urban	0	0
Low Density Residential/Urban	1	1
Forested	1	4
Agricultural or Open Space	4	3
Overall Suitability Rating[4]		
Low	< 15	<15
Moderate	15 – 25	15 – 25
High	25 - 35	25 - 35

Note: The higher the maximum number in each characteristic, the more important the characteristic; the higher the ranking, the greater the suitability.

1) Depth of the profile to bedrock
2) Excluded; rated as poor
3) Permeability of the most restrictive layer
4) Sum of values

2.1.3 Topography

Topography refers to the configuration of the land surface and may be described in terms of elevation, slope, relief, aspect and landscape position (Birkeland, 1984; Brady and Weil, 2002). Site topography is also important in land application practices because:

- Topographic low positions accumulate water from higher adjacent areas and may have higher moisture contents, shallow ground water, and/or greater salinity,
- The natural horizontal movement of ground water usually follows the ground slope,
- Erosion and runoff potential increase with increasing slope; and
- Slope orientation or aspect affects the absorbance of solar energy.

2.1.3.1 *Topography and Soil Development*

The distribution and properties of soils in the landscape are strongly influenced by topography because of the resulting differences in microclimate, soil-forming processes and geological surficial processes. For example, steep slopes generally encourage surface erosion and allow less rainfall to enter the soil prior to runoff. Therefore, the depth of soil development on steep terrain is generally limited. The opposite condition is found in soils in flat flood basin areas, which tend to be deep and fine textured.

2.1.3.2 *Topography and Vegetation*

Southerly and westerly slopes receive higher amounts of solar energy. Plants start growing earlier in the spring and have a potential of less frost damage in the spring and fall. Sites in low pockets with higher adjacent areas may have a higher potential for cold air accumulation and frost damage. North and east slopes usually accumulate more snow. Snow accumulations on these positions last longer and result in somewhat shorter growing season. Toe slope positions accumulate water from higher elevation and potentially have higher moisture and possible high water tables.

2.1.3.3 *Topography, Slope and Land Use*

The more level topography present, the fewer difficulties in the construction, operation and maintenance of a land treatment system. Potential land treatment sites that have a slope of less than 2% are considered to be the most suitable. As slope increases, it is harder to evenly distribute the wastewater. Sites with slopes above 15% are severely limited and may not be acceptable for wastewater application without special care in both design and operation (see Table 2-5).

In general, the maximum slope recommended for cultivated agriculture is 12 to 15 percent (Pettygrove and Asano, 1985; EPA 2006). It may be possible to adapt crops that do not require cultivation, such as grass-hay, or grapes, to slopes of 15 to 20 percent or more, depending on site-specific runoff constraints. The ranking of slope (or grade) as it affects site suitability is shown in Table 2-5. Moser (1978) also provides grade suitability factors for slow rate agricultural and forest systems. These are in Table 2-6 below.

Table 2-6. Grade Suitability Factors for Identifying Land Treatment Sites (Moser, 1978)

Grade (%)	Agriculture	Forest
0 – 12	High	High
12 – 20	Low	High
> 20	Very Low	Moderate

Topography may also influence moisture content and the depth to ground water tables. In wet or humid climates, topographic low positions may accumulate moisture from upland areas resulting in a high water table. In arid or semiarid climates, soluble salts derived from weathering in upland areas often naturally accumulate in low-lying areas.

2.1.4 Geology and Hydrogeology

The site-specific geology and hydrogeology are critical components of the land application site. These factors determine the fate of water and constituents that leach through the soil to ground water. A hydrogeologic investigation should be conducted on sites being considered for wastewater land treatment. The following section discusses objectives, scope and content, and elements of hydrogeologic investigations at both prospective and existing wastewater land treatment sites.

2.1.4.1 *Objectives of a Hydrogeologic Investigation*

Conducting hydrogeologic investigations is discussed in numerous texts, including USBI Bureau of Reclamation (1977) and EPA (1993).

This section describes how to conduct a hydrogeologic investigation for a wastewater land treatment site. The purpose of such an investigation is to characterize the regional and local hydrogeologic environment with respect to the wastewater land treatment facility and potential or actual impacts from that activity.

The investigation can be submitted as part of a permit application, and can be used to establish permit conditions. The investigation also helps determine the level of monitoring necessary to evaluate both site management effectiveness and compliance, and accurately assess the facility's impact on ground water quality. The investigation is critical to designing a monitor well network including monitoring well locations and well construction plans.

See Section 7.2 for further discussion of ground water monitoring.

2.1.4.2 *Scope and Content of the Hydrogeologic Investigation*

The scope of work for a hydrogeologic investigation as well as DEQ expectations should be discussed with DEQ prior to conducting an investigation. The scope of a hydrogeologic investigation should be determined based upon the complexity of the facility, wastewater characteristics and loading rates, the site characteristics and potential for ground water quality degradation by the facility.

Not all of the elements discussed below are necessary in all cases. For facilities that are not anticipated to have a substantial impact on the environment, a less intensive hydrogeologic investigation may be appropriate. For sites where information is available, the investigation could be completed through a literature search and description of the site and the proposed activities. Literature would include geological, hydrogeological, and ground water quality studies and reports. Lesser detail would be necessary on simple municipal sites having low hydraulic and constituent loading rates. In some cases the need for an investigation may be waived by DEQ. More detail would likely be needed for larger and more complex facilities that land apply at higher constituent and/or hydraulic loading rates.

The following section discusses information that should be addressed in a hydrogeologic investigation as necessary depending upon the activity and the complexity of the site:

- Geology
- Hydrogeology
  - Hydraulic conductivity and transmissivity
  - Ground water depth, gradient and flow direction
  - Location and construction of existing wells
  - Contaminant transport
- Ground Water Quality
  - Ambient ground water quality
  - Beneficial uses of ground water
- Related Information
  - Waste characterization
  - Area of potential or actual impacts
  - Surface water
  - Contaminant source inventory

Additional information may be needed should DEQ determine that it is necessary to adequately characterize the site. The criteria used to determine the detail of the hydrogeologic characterization necessary are discussed in the following. The following elements are typically addressed when conducting a hydrogeologic investigation to characterize a wastewater land treatment site.

2.1.4.2.1 *Geology*

The hydrogeologic layers and other subsurface structural information helps characterize contaminant movement and behavior prior to reaching ground water and provides an indication of risk to existing beneficial uses of ground water from constituents in percolate. The geology of a site should be characterized through the interpretation of well logs, geologic maps, and cross sections. Cross sections can be constructed from information contained in drillers' logs and geological reports. Figure 2-6 shows the generalized geology of Idaho. Detailed geological maps of specific Idaho counties can be found at the following web site:

http://imnh.isu.edu/digitalatlas/

Structural Features

Structural features should be delineated, such as faults, fractures, fissures, impermeable boundaries or other subsurface features that might provide preferential pathways for, or otherwise influence, contaminant migration. Fracture zones that extend up to the wastewater application site can provide a more direct path for percolate to reach water supply wells, compared to massive material. The presence of fracture zones may necessitate a more conservative monitoring well network design (see Section 7.2 for further discussion). Fracturing due to rapid contraction at the surface while cooling is characteristic of extrusive igneous rocks, often resulting in high water yielding formations such as the Snake Plain Aquifer. Drilling logs and completion information for nearby production wells can provide information on fracture zones in the bedrock.

Bedrock

Bedrock depth, thickness, kind, permeability and characteristics (i.e., fractured, weathered, solid, dense, tilt or slope) of underlying unconsolidated material (including sediments, alluvium, gravel and sand) should be identified, along with any other characteristics of the vadose zone that effect movement of water (EPA, 1993). Shallow bedrock can affect site planning and monitoring. Depth to bedrock, soil characteristics down to bedrock, and slope will determine hydraulic loading capacity of the site and the potential for percolate to resurface downhill from the site. Observation or exploratory wells may need to be drilled to better define the hydrogeologic framework of a site where adequate information is not available. Such wells may or may not be suitable for use as monitoring wells however. The presence of aerobic or anaerobic conditions should be noted.

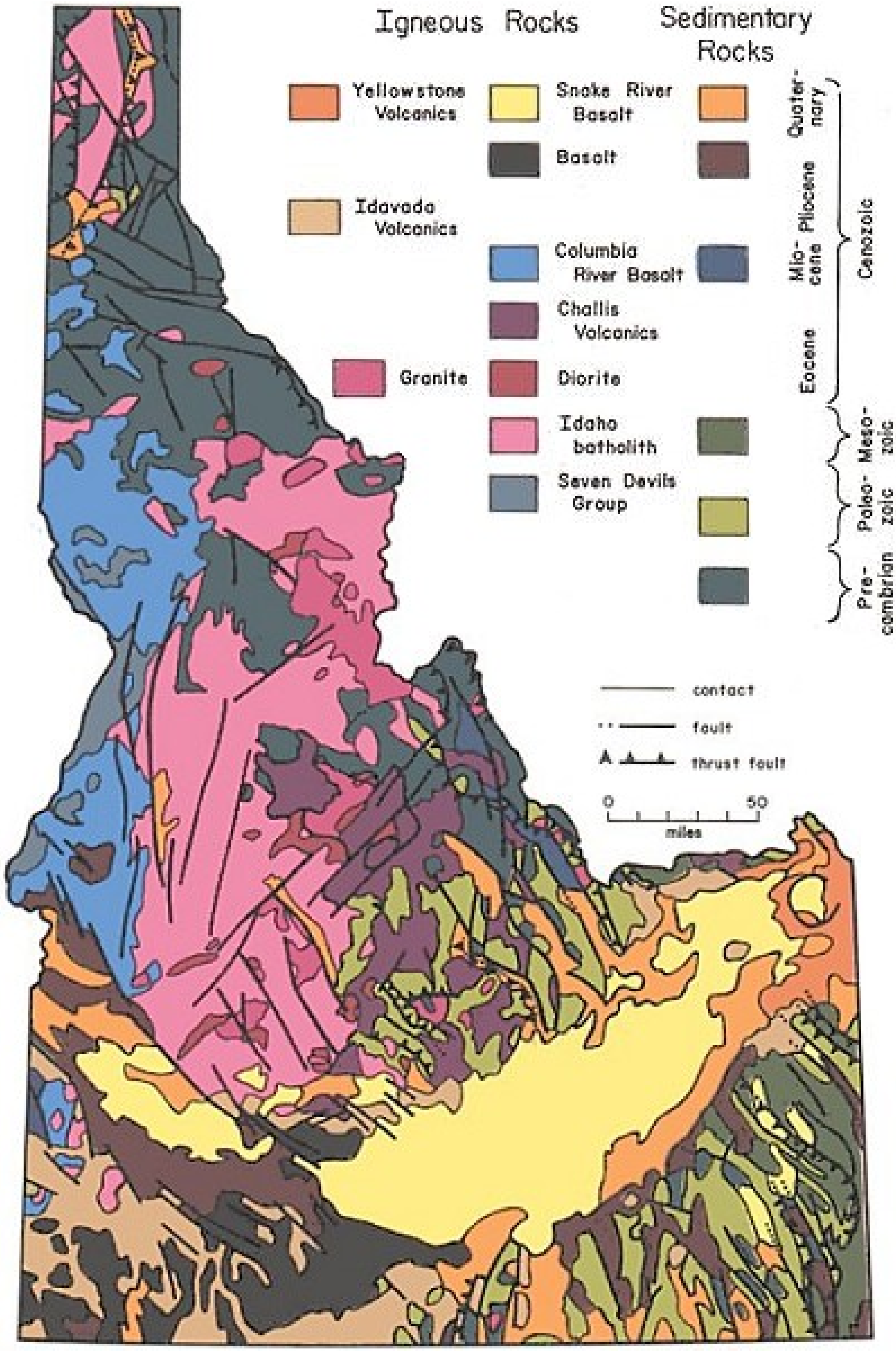

Figure 2-6. Geological Map of Idaho. Copyright 2006 by Andrew Alden, geology.about.com, reproduced under educational fair use."

Limiting Layers

The degree to which a given lithologic unit acts as a barrier (aquiclude) or transmitter (aquifer) depends on its porosity and permeability. Thick zones of low permeability beneath the site typically lessen the potential risk of ground water quality impacts to the beneficial uses. Depth to and thickness of limiting layers may effect the usefulness of the site as they affect the mounding potential of water below the site. An understanding of the hydrologic structure also is important to consider when planning a ground water monitoring program. In particular, it is important when determining whether deeper sand or gravel zones should be monitored and existing production wells be incorporated into a ground water monitoring program.

Geomorphology

The geomorphology of the area should be described including the topography and drainage patterns. The soils on the site should be identified and described by type, horizontal and vertical extent, infiltration rate, organic matter content, and mineralology. Hardpan characteristics should be identified. If a hardpan underlies the existing site, it could provide an impediment to the downward flow of percolate. This would provide additional protection for ground water quality. The soil immediately above a hardpan will also tend to stay in a more saturated condition. This could limit hydraulic loading, but could enhance nitrogen removal. It will also affect the interpretation of soil and vadose zone monitoring. See Section 2.1.2 for further discussion of soils characterization.

2.1.4.2.2 *Hydrogeology*

Aquifer types underlying wastewater land treatment sites in Idaho include basalt, alluvial, mixed volcanic, and sedimentary (Figure 2-7). Understanding how ground water moves under a land application site and transports dissolved constituents can be important when interpreting ground water monitoring results (Section 7.2). While a detailed discussion of ground water hydrology and contaminant transport is beyond the scope of this document, this section presents the types of aquifer parameter data that should be obtained and how the data can be used. Characterizing initial ground water quality and beneficial uses is also discussed.

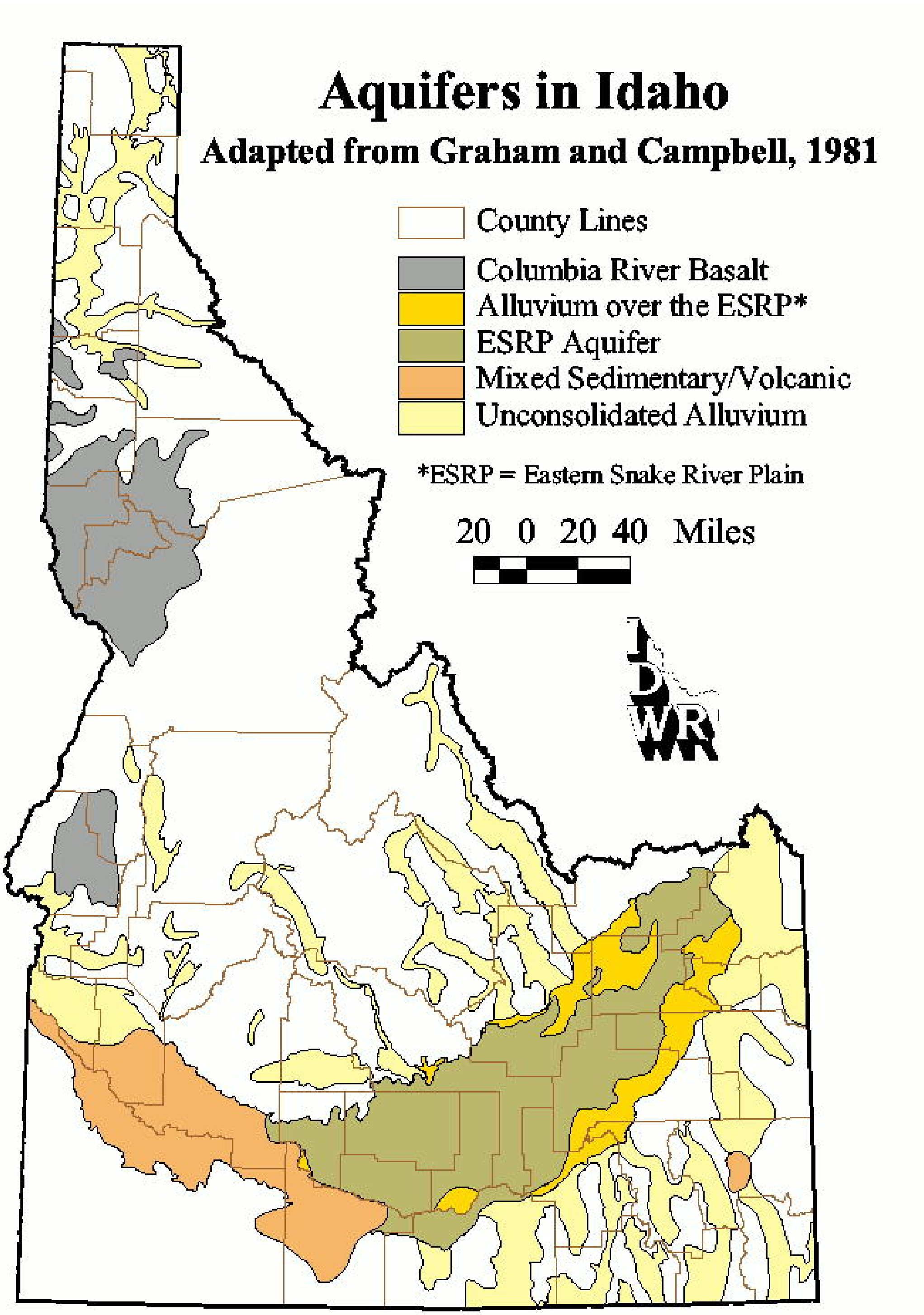

Figure 2-7. Map of major aquifers in Idaho (DEQ, 1997).

Hydraulic Conductivity and Transmissivity

Ground water velocity varies directly with the gradient (difference in ground water surface elevation divided by the distance between monitoring wells), effective porosity, and the lateral hydraulic conductivity of saturated materials.

Sources of Aquifer Parameter Information

Ranges of values for hydrogeologic parameters should be determined. Parameters include hydraulic gradient (Section 2.5.3), ground water velocity, transmissivity (Sections 2.5.3 and 2.5.4), storage coefficient, hydraulic conductivity (Sections 2.5.3, 2.5.5, 2.5.6, 2.5.7, and 2.5.8), porosity (Sections 2.5.3 and 2.5.9), and dispersivity.

These hydrogeologic parameters are used to characterize contaminant movement in the aquifer and to assess the area potentially impacted by the facility's activities. Very approximate estimates for hydraulic conductivity and specific yield can be based on aquifer material texture from driller's logs. Laboratory evaluation of drilling core samples for texture and hydraulic conductivity provide more accurate results. Ground water flow and direction(s) should be identified. Hydrographs and equipotential maps should also be included if available. Precipitation and evapotranspiration rates should be identified for the area to help characterize ground water recharge.

Aquifer Testing

The best hydraulic conductivity data is usually obtained from pumping and recovery tests of site monitoring wells. Depending on the information available for an area, aquifer testing may be necessary to characterize aquifer transmissivity/hydraulic conductivity. Testing methods for particular aquifer types (confined, unconfined, leaky confined, etc.) are discussed in several texts, including USDOI Bureau of Reclamation (1977). Analysis of test data is also discussed in numerous texts and will not be addressed here. It is critical to insure that the particular aquifer test method is appropriate for the site-specific conditions.

There are instances when certain tests are unsuitable for the aquifer conditions present. For example, it is not uncommon for slug tests to be conducted on wastewater land treatment sites because they are relatively simple and inexpensive. Slug tests characterize the hydraulic properties near the well bore. This area may be significantly altered during well construction and thus not be representative of the aquifer matrix (Moench and Hsieh, (1985). Slug tests might not be appropriate in highly transmissive aquifer materials. Response times (change in head vs. time) can be very rapid - only a few seconds in duration - and may indicate that the volume of the aquifer being stressed is very small, perhaps only the sand pack around the well screen. Rapid response times may not provide the data needed for valid data analysis to be done. Pump tests, which stress larger volumes of the aquifer, although more involved, likely will yield more representative results.

Proposed aquifer testing methods and analysis on permitted wastewater land treatment sites should be discussed with DEQ prior to conducting them. Methods should be researched adequately to determine applicability to a given site-specific application.

Ground Water Depth

The depth of first encountered ground water is important in planning for site loading rates and site monitoring. A shallow depth to ground water can limit the hydraulic loading rates and the soil zone treatment effectiveness. Generally, the potential for contamination is greater in sites with water tables at less than five feet. Shallower depths to ground water may require subsurface drainage unless shallow ground water occurs only during non-land application periods and permanent crops susceptible to damage from poor drainage are not grown. Depth to ground water and seasonal variance is critical for deciding where to screen monitoring wells.

Ground Water Gradient and Flow Direction

The direction of ground water movement and gradient can be determined by mapping the static water level recorded from area wells. This is necessary to establish the directions that contaminants would migrate if introduced into the environment. Water level elevations should be monitored on a monthly or quarterly basis from a reasonable number of wells for a period of time sufficient to determine seasonal variations in ground water flow and temporal ground water elevation trends.

Seasonal water level fluctuations in the uppermost aquifer may occur and should be taken into account when developing permit conditions. Seasonal water table elevation can sometimes be detected in the soil horizon by identification of mottled soil. A ground water potentiometric map illustrating ground water flow directions should be prepared for aquifers that have a potential to be contaminated by wastewater land treatment activities. Temporal trends, if observed, should be characterized along with seasonal variability.

Data to determine flow direction and ground water gradient should include locations of wells, dates of measurements, locations of measuring points relative to the land surface elevation, depth to water, time since the wells were last pumped, other area wells which were pumping during the measurement, and any available construction data such as total depth and screened interval. A contour map should be prepared from the resulting information. Ground water divides should also be noted.

A triangulation of observation wells within the same hydrogeologic unit is needed to determine the horizontal component of flow. Therefore, a minimum of three observation well installations are necessary. This practice helps describe the general direction of ground water flow in a relatively simple hydrogeologic setting. Paired wells (wells located adjacent to each other, but screened in separate aquifers) may be needed to define the vertical component of ground water movement, and therefore the potential for contaminant movement, from upper to lower aquifers, and also to determine the ground water flow direction in upper and lower aquifers. Additional information related to site characterization, well location and number of wells may be obtained from Ogden (1987).

Monitoring of multiple aquifers to determine vertical gradient requires nested or cluster wells. Data on ground water levels in nearby wells can be used in certain circumstances to help establish vertical ground water flow gradients. An average upward vertical gradient in ground water may also lessen the risk to existing ground water beneficial uses. Conversely, evidence of significant hydraulic connectivity between shallow ground water and aquifers tapped by water supply wells could indicate a greater risk to beneficial uses and the need for a more conservative system design. See Section 7.2 for further discussion of monitoring well network design.

Leaching to the subsurface can cause ground water mounding, depending on the rate of leaching and subsurface lithology. Mounding can influence the local hydraulic gradients, which may impact the effectiveness of the monitoring wells. The potential of a discharge to alter the gradient due to ground water mounding should be evaluated prior to developing a monitoring plan.

Location and Construction of Existing Area Wells

The location, construction details, and screened interval(s), depth, pumping rates, static water level, geologic information from drillers logs, and hydrogeologic position (up-gradient versus down-gradient) of all water wells within ½ mile of sites should be obtained and evaluated as part of the hydrogeologic investigation of a proposed wastewater land treatment site. This information can be useful in characterizing local geologic and hydrogeologic conditions and shallow or deep aquifers currently or previously utilized as a water source(s). Such data may also be used to assess baseline water quality, develop potentiometric maps, and assist in the design of ground water monitoring wells to be constructed on site. For example, if nearby wells are completed and screened within deeper aquifers, this may indicate that shallow ground water is not capable of yielding economically significant quantities of water to wells (IDAPA 58.01.11.007.02) and/or is of poor quality. Additionally, existing water well data may indicate that multiple aquifers are being utilized and may need to be monitored.

Plans and specifications of all proposed monitoring wells should be submitted to DEQ for review of location and design prior to installation. (Guidelines for monitor well design are discussed in Sections 7.2 and 7.7.3) The assessment of the vulnerability of domestic and municipal wells is discussed in Section 6.6.4.

Contaminant Transport

Understanding how ground water moves under a land treatment site and transports dissolved constituent is important both in interpreting ground water quality data and in predictive modeling. Contaminant transport modeling may be necessary to make preliminary assessments of the feasibility of a proposed activity in a particular hydrogeologic setting. California EPA (1995) has useful guidance for utilizing modeling for hydrogeologic characterization, including identifying objectives, model selection, documentation, and interpretation of results. Other means to characterize, or find evidence of, contaminant transport include ground water age studies, analysis of common ion chemical signatures, and tracer studies.

Determining the average age of ground water can be useful for estimating what portion of a particular ground water sample has been impacted by land application site operations. High accuracy tritium, helium-3, and chlorofluorocarbon (CFC) analysis of ground water samples can provide information on ground water age for ground water less than 60 years old, and can indicate whether a ground water sample is more than 60 years old. The mix of ions in water can provide a characteristic signature that can often be related to the recharge source of ground water. This can be important when determining if applied wastewater is a main component of the ground water from a given monitoring well. Environmental isotopes (non-radioactive isotopes) are also used to determine origin of ground water contamination. Isotopes of oxygen (^{18}O), hydrogen (^{2}H: deuterium), and nitrogen (^{15}N) can be used. See DEQ (2003b) for application of environmental isotopes to ground water impacts and both industrial and municipal wastewater land treatment. Stiff or Piper diagrams provide a visual method to help characterize and group water from monitoring wells.

The mix of ions in water can provide a characteristic signature that can often be related to the recharge source of ground water. This can be important for characterizing initial ground water quality and for subsequently determining whether, and to what degree, applied wastewater is influencing the ground water from a given monitoring well. As discussed in greater detail in Section 7.2.4.2.3, Stiff or Piper diagrams provide a visual method to help characterize ambient conditions and possible contaminant influences of ground water from monitoring wells.

Tracers can be used to see how quickly applied water reaches ground water monitoring wells. An ideal tracer is one that is mobile, low in concentration in monitoring wells, and not a water quality concern at the concentrations needed for tracer use. Iodide, bromide, and boron have been used effectively as ground water tracers, although bromide and boron can have water quality limit concerns. Tracers should only be used when there are significant apparent water quality impacts at a site and ground water transport cannot be explained using the other tools described in previous paragraphs.

2.1.4.2.3 *Ground Water Quality*

The following sections discuss definitions and determination of site background (or ambient) ground water quality and consideration of beneficial uses in wastewater reuse site characterization and evaluation.

Ambient Ground Water Quality

Ambient ground water quality can be defined as either natural or site background water quality conditions. The difference in quality between these two designations is as follows:

- **Site Background (water quality) Level**. The site background (water quality) level is defined as the ground water quality at the hydraulically up-gradient site boundary (IDAPA 58.01.11.007.25).
- **Natural Background Level.** The natural background (water quality) level is defined as the level of any constituent in the ground water within a specified area as determined by representative measurements of the ground water quality unaffected by human activities (IDAPA 58.01.11.007.19).

The ambient ground water quality characterization constitutes some of the most important information collected in the hydrogeologic investigation. The site background ground water quality characterization documents the condition of the ground water resource up-gradient of a currently operating facility or the condition at up-, cross-, and down-gradient locations prior to its operation. This characterization provides part of the basis for wastewater treatment design and enables future evaluation of the activity on ground water quality. It is important to accurately characterize background water quality for comparative purposes during facility operation. DEQ can establish site-specific ground water quality levels (IDAPA 58.01.11.400.05) for the purposes of establishing permit limits and early warning limits on a site-specific basis. This is done by using current site background water quality data (IDAPA 58.01.11.007.25.

Existing wells may be used to characterize ambient ground water quality and establish a baseline for the evaluation of long term monitoring data if the wells are properly constructed, if the wells are completed in the aquifer of interest. The quality of first encountered ground water is typically the more important of the aquifers in planning for site loading rates and site monitoring. Wells must yield representative samples of ambient ground water. If there are no existing wells located in the uppermost aquifer, or existing wells are inappropriately located with respect to wastewater land treatment activities, then monitoring wells should be installed to assess ambient conditions.

Existing data from appropriately located and constructed wells can be used for determining background water quality if the data are reasonably current. Typically the most recent 10 years of data are considered current.

Ground water quality should be characterized for the constituents of concern (Table 2-7), as these constituents vary both temporally and seasonally. The constituents of concern are the chemicals that are land applied or mobilized as a result of land application. In addition, the basic inorganic chemical parameters (common ions) should also be characterized. See Sections 7.2.4 and 7.2.4.2.3 for further discussion of monitoring parameters and common ions respectively.

A minimum number of samples are needed to characterize background water quality. Individual ground water samples are only representative of ground water quality at a particular time in a particular location. Therefore, one ground water sample cannot be assumed to be representative of ground water conditions throughout the site or over a period of time. Since ground water quality often varies seasonally or changes with time (temporally) due to other influences, the greater the number of samples collected over time, the more representative the characterization. Sufficiently large sample populations increase confidence in determinations of ground water quality impacts.

Monitoring frequency of background water quality is important for characterizing the variability in ground water quality over time. For establishing background water quality, typically eight samples collected over a period of at least one year, with no more than one sample collected during any month in a single calendar year, are necessary to statistically determine seasonal variability and optimal sampling frequency (Barcelona et al. 1989; Barcelona et al. 1985; EPA, 1992) and to establish baseline ground water quality data prior to initiation of land application of wastewaters. However, DEQ (2003a) should be consulted for more program-specific detail.

The initial rounds of sampling are the most critical; they provide a basis for determining the effects of the activity's operations and the actual impacts on the environment. Background water quality samples should be collected and results submitted as part of the permit application. Background water quality is statistically determined based on the procedures described in DEQ (2003a).

It is sometimes difficult to collect sufficient background samples prior to issuing a permit. In some cases additional background water quality samples may be collected after the permit has been issued. Again, DEQ (2003a) should be consulted. The determination of suitable wells for background water quality monitoring should be determined based upon flow characteristics in the aquifer.

Beneficial Uses of Ground Water

All existing and future beneficial uses for ground water should be identified for the area, which may have potential to be impacted by the facility's wastewater land treatment activity. Beneficial uses are defined in the Ground Water Quality Rule (GWQR) IDAPA 58.01.11.007.03 as “various uses of ground water in Idaho including, but not limited to, domestic water supplies, industrial water supplies, agricultural water supplies, aquacultural water supplies, and mining. A beneficial use is defined as actual current or projected future uses of ground water.”

Determination of beneficial use impairment should consider impairment of interconnected surface water uses as well as ground water uses. If additional parameters need to be monitored in order to protect an identified beneficial use, then those should be incorporated into both wastewater and ground water monitoring plans. Beneficial uses of ground water can be evaluated by identifying land ownership, land use, zoning restrictions, and well water use in the surrounding area. Source water assessments for municipal drinking water systems, typically prepared by DEQ, should be consulted as available. See the DEQ website for further information on source water assessments in Idaho: http://www.deq.state.id.us/water/prog_issues/source_water/assessment.cfm.

Future beneficial uses should also be projected if possible.

2.1.4.2.4 *Related Information*

The following section discusses information related to hydrogeologic investigations, which should be considered. Topics include waste characterization, area of potential or actual impacts, surface water, and compiling a contaminant source inventory.

Waste Characterization

Potential impacts to the environment can be assessed in part by characterizing the quantity and the quality of the waste prior to operation. Facilities should analyze their effluent for those chemical, physical, and biological constituents, which are expected to be in their waste stream. New facilities that have not yet been constructed can make preliminary predictions of the quality of their effluent by analyzing waste streams from similar types of operations. Constituent concentrations and variability, volume, rate, and frequency and duration of wastewater land treatment activity should be described.

Table 2-7 describes common wastewater characteristics of different types of facilities. This is a general list of constituents and should not be considered a comprehensive list. This list provides a base to consider in evaluating wastewater parameters and delineating the constituents of concern that could impact ground water quality. See Section 7.2.4 for further discussion of ground water monitoring parameters.

Table 2-7. Common constituents of concern in ground water for different wastewater land treatment facilities.

Activity	Typical Constituents Of Concern for Ground Water Monitoring
Municipal Facilities	NO_3, TDS,
Cheese Processors	NO_3, TDS, Na, Cl, Fe, Mn
Sugar Beet Processors	NO_3, TDS, Cl, Fe, Mn
Potato Processors	NO_3, TDS, Cl, Fe, Mn

Wastewater impoundments, whether lined or unlined, generally have the potential to contaminate ground water. All liners leak to some extent. The amount of seepage is dependent upon the permeability of the liner material, the thickness of the liner, the depth of the water in the impoundment and the surface area of the liner.

The potential to contaminate ground water should be evaluated to determine if ground water monitoring or additional protection measures are necessary. The potential to contaminate ground water can be assessed by evaluating the volume and concentration of leachate discharged to the aquifer and thus the mass loading of contaminants infiltrating to ground water. The mixing characteristics of the aquifer and percolate should also be assessed. Impoundments that have double synthetic membrane liners with a leak detection system are not generally considered to have a potential to contaminate ground water. See IDAPA 58.01.16.493 for rules concerning wastewater lagoons, and related guidance in Section 6.3.

Area of Potential or Actual Impacts

The area potentially affected by contaminant migration should be described. This is the area that may be affected, either chemically, physically or biologically as a result of wastewater land treatment activities. The area impacted should take into account advection, dispersion, and diffusion of contaminants in ground water. The size of the area will depend upon wastewater quality, volume applied and rates of application, site characteristics and management, aquifer characteristics including mixing characteristics. The applicant can use flow, transport and mixing zone modeling to help describe these areas.

The location of the facility should be illustrated on both a 7.5 minute topographic map, as well as a more detailed map of the facility. Site plans should be submitted that are drawn to approximate scale. Site maps should include the following: property lines, buildings, structures, locations of wells, locations of other underground conveyance systems (i.e., underground storage tanks, septic systems, water lines, gas lines, etc.), location of geologic borings, wastewater land treatment facilities, topography, land ownership or uses of the adjacent property, and any other relevant information.

Other areas of designation should also be identified, such as; Idaho Department of Water Resources (IDWR) Ground Water Management Areas, DEQ Nitrate Priority Areas, Sole Source Aquifers, Sensitive Resource Aquifers, Wellhead or Source Water Protection Areas, and Critical Aquifer Recharge Areas. Previous land use should be identified to determine what, if any, contaminants may be present in the subsurface. Consideration should be given to those activities that have a potential to mobilize contaminant constituents already present in the environment.

Surface Water

Surface water bodies including lakes, reservoirs, wetlands, streams and the 25 year flood plain should be delineated on a 7.5 minute topographic map within a 1 mile radius of the facility. The possible interaction between surface and ground water should be assessed for the potential of impacted ground water contaminating surface water. Irrigation water quality should also be characterized.

Contaminant Source Inventory

Sources of potential or actual contamination in the local area of a wastewater land treatment facility should be inventoried. Knowledge of these sources is important in the interpretation of ground water data. Pre-existing contamination and its source can be identified prior to wastewater land treatment activities taking place.

2.2 Cropping

A healthy vegetative cover is essential for a wastewater land treatment system to effectively treat wastewater. Characteristics of crops that impact their use in land treatment are described in this section. These include water use, nutrient needs and uptake, and tolerance for trace constituents. Guidance on crop selection and management for land treatment process is also provided.

2.2.1 Crop Selection

The primary role of vegetation in a land treatment system is to recycle nutrients in the wastewater into a harvestable crop. Plant uptake is not the only form of nutrient transformation or removal from the soil-plant systems utilized in land treatment, but plant growth does impact most mechanisms either directly or indirectly. Plants also play a role in stabilization of the soil matrix and help maintain long-term infiltration rates. In slow rate systems designed for agricultural reuse, nitrogen generally is the limiting nutrient.

Varieties (cultivars) of major grain, food, and fiber crops are bred specifically for different regions of the United States because of differences in growing seasons, moisture availability, soil type, winter temperatures, and incidence of plant diseases. Other regional issues include infrastructure for post-harvest processing and demand for harvested by-product. A regional approach, therefore, is generally recommended for selection and management of vegetation at land treatment sites (Jensen et al., 1973). One of the easiest methods for determining regional compatibility is to investigate the surrounding plant systems.

Once regional issues are considered, the final criteria should be based on specific system objectives including nutrient uptake, cultural practices, season of growth, compatibility with hydraulic loading (quantity and timing), and salt tolerance. Although plant uptake is not the only form of nutrient transformation that takes place in the soil-plant system, plants are often selected for their propensity for uptake of a certain nutrient or for use of large quantities of water.

2.2.2 Crop Management

In order to reuse and remove nutrients applied from wastewater land treatment, the crop must be harvested and removed from the treatment site. Harvesting operations should be conducted when soil moisture conditions are below field capacity. If a site is mismanaged and the vegetation dies, the site will not be as effective in treating the wastewater. There should be consideration given in nutrient management planning for the fate of nutrients in those sites where vegetation is not harvested.

Many land treatment sites in Idaho are forested or have native grasses and shrubs. Silvicultural plans for forest/tree sites should be up-dated at approximately five-year intervals. These plans should be prepared by a qualified silviculturist and describe necessary management techniques and recommend harvest cycles.

Plans should include the following items (Inland Forest Management, Inc. 1995):

- Use of long-term, forest management principles
- Minimization of surface water flow by proper irrigation scheduling and maintaining vegetative cover
- Maintenance or enhancement of water quality
- Maximization of productivity of the forest resource
- Protection of the forest resource from insect, disease, and fire hazards

In addition, fate of nutrients in unharvested materials, such as slash and vegetative understory, is important to consider at silvicultural sites. Both EPA (2006; Chapters 4 and 5) and Crites et al. (2000; Chapters 5 and 6), provide important land treatment site characterization guidance for forested sites.

2.2.3 Evapotranspiration

Evapotranspiration (ET) is the sum of plant transpiration and evaporation from plant and soil surfaces and is also known as crop water use (Doorenbos and Pruitt, 1977). As commonly defined, ET does not include other components of irrigation inefficiency or losses such as deep percolation, wind drift, droplet evaporation in the air, and run-off.

Sophisticated computer models can be used to estimate separate transpiration and evaporation components of ET. However, site-specific data for reference ET is often available. Crop ET based on reference ET adjusted for a specific crop is sufficiently accurate for water balances and irrigation scheduling (Allen et al., 1998). See Section 4.1.1.2.2 for further discussion of sources of ET values.

2.2.3.1 *Transpiration*

Transpiration is the water that passes from the soil into the plant roots. Less than one percent of the water taken up by plants is actually consumed in the metabolic activity of the plant (Rosenberg, 1974). The remainder passes through the plant and leaves as vapor through the openings in the leaves known as stomata.

The drier and hotter the air, the higher the transpiration rate will be. The drier the soil, the slower the transpiration will be, because the water is held more tightly by the soil. A specific plant variety will have a genetic potential to transpire a certain quantity during the growing season. The transpiration on a given day depends on the plant growth stage, weather conditions, the availability of water, and general plant health. Non-plant based models used to calculate ET assume that evapotranspiration is not impacted by plant health or water stress.

2.2.3.2 *Evaporation*

Evaporation is water converted from liquid to vapor that does not pass through the plant. Evaporation may occur from wet soil or plant surfaces. When plants are young, a large portion of ET is evaporation from the soil surface. When plants achieve 70 to 80 percent canopy cover, soil evaporation will amount to only 10 to 25 percent of the ET. The ET due to soil evaporation primarily occurs immediately after irrigation when the soil surface is wet as illustrated in Figure 2-8.

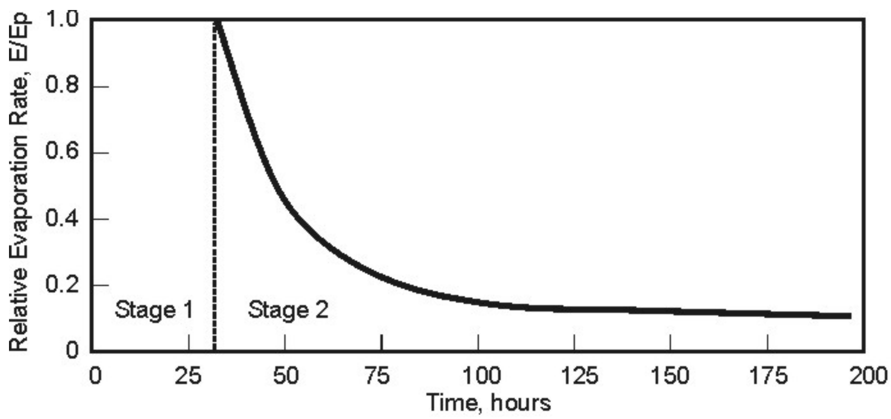

Figure 2-8. Evaporation from bare soil that was initially wet (Hanks and Retta, 1980).

Evaporation from the soil is increased by maintaining moist surface conditions. Figure 4-9 shows increases in the value of K_c (indicating higher ET rates) when frequency of wetting is increased. See further discussion of K_c and ET in Section 4.4.9. Surface or sprinkler irrigation losses are similar to drip irrigation. With drip irrigation a small percentage of the surface is wet all the time compared to surface and sprinkler irrigation that has a large percentage of the area wet for only a small amount of time. The extremes can be represented by sub-surface drip, which has very little evaporation, and small frequent sprinkler applications, which can evaporate a high percentage of the applied water. In the latter case, only the plant canopy and soil surface are wetted, and most of the applied water is lost to evaporation with little if any infiltration into the soil.

2.2.4 Crop Nutrients

Plant nutrition is critical to successful utilization of crops and other vegetation for wastewater land treatment. This section discusses nutrients with respect to crop needs, availability, uptake, and management. Although not a nutrient per se, salt uptake is also discussed as it has important implications for crop health and both soil and ground water quality.

2.2.4.1 *Crop Nutrient Needs*

Plants require at least 16 elements for normal growth and for completion of their life cycle. Carbon, hydrogen and oxygen are the elements used in the largest amounts; these are non-mineral elements that are supplied by air and water. Plants obtain the other 13 elements from the soil or from amendments added to the soil (fertilizers or wastewater).

2.2.4.1.1 *Macronutrients*

Plants need relatively large amounts of nitrogen, phosphorus, and potassium. These nutrients are the ones most frequently supplied to plants by fertilizers. Calcium, magnesium, and sulfur are required in somewhat smaller amounts. These six elements, along with carbon, hydrogen and oxygen, are considered *macronutrients*.

2.2.4.1.2 *Micronutrients*

In contrast to these macronutrients, the *micronutrients* consist of seven essential elements: boron, copper, chlorine, iron, manganese, molybdenum, and zinc. These elements occur in very small amounts in both soils and plants, but their role is equally as important as the macronutrients. A deficiency of one or more of the micronutrients can result in severe reductions in growth, yield, and crop quality.

Some soils do not contain sufficient amounts of these nutrients to meet the plant's requirements for rapid growth and good production. In such cases, supplemental micronutrient applications in the form of commercial fertilizers or foliar sprays should be made.

2.2.4.2 *Nutrient Availability*

All essential nutrients must be available, continuously, and in balanced proportions, to support photosynthesis and other metabolic processes of plants. If any one of these essential elements is missing, plant productivity will be limited, or the plant may cease to grow entirely. The principle of *limiting factors*, which states that the level of production can be no greater than that allowed by the most limiting of the essential plant growth factors, applies in both cropping systems and in natural ecosystems. This section discusses the chemistry of available nutrients and factors affecting nutrient availability.

2.2.4.2.1 *Chemistry of Available Nutrients*

Although the soil contains large amounts of nutrients, only a small percentage of these amounts exist in chemical forms that are available to plants. Nutrients can exist in several forms in the soil.

- Soil solution nutrients are readily available to plant roots.
- Adsorbed cations exchangeable with those in soil solution **are** moderately available.

- Cations in structural framework of clays and organic colloids can move in time to the adsorbed state and are slowly available.
- Cations in the rigid structural framework of minerals and organic tissue are released only on weathering or decomposition, and are very slowly available. Most nutrient cations are in this component, the least are in the soil solution (Brady 1990).

Generally, plants can only absorb nutrients when they are in the form of an ion. For example, soil nitrogen occurs in organic and inorganic forms, in solution and as a gas, and as the cation ammonium (NH_4^+) and the anion nitrate (NO_3^-). Plant roots absorb only ammonium and nitrate forms of nitrogen.

Plant-available forms of potassium, calcium, magnesium, manganese, zinc, iron and copper occur as cations. Potassium and ammonium both have a single positive charge, while the remaining cations have two or more positive charges. In general, these positively charged nutrients are adsorbed onto soil colloids (as described in Section 2.1.2.2.2) and are not subject to leaching under normal conditions. The higher the charge of a cation, the more strongly it is attracted to the negative charge sites of the soil. However, when the sum of the positively charged nutrients exceeds the soil's capacity to hold nutrients, these nutrients may be lost through leaching.

One form of plant-available nitrogen is nitrate (NO_3^-). The plant-available form of chlorine is the anion chloride (Cl^-). Both of these anions are repelled by the negative charges of soil colloids. Therefore, they are readily leached when water passes through the soil.

The plant-available forms of sulfur (sulfate: SO_4^{2-}) and molybdenum (molybdate: MoO_4^{2-}) are anions and are also repelled by negatively charged soil colloids. However, these anions may react weakly with positively charged sites, such as occur on iron oxides. Even though these elements are not strongly bound to soil colloids under normal conditions, they do not leach as readily as nitrate and chloride, and are frequently observed to increase in subsoil horizons having higher clay content and lower pH.

Plant-available phosphorus occurs as an anion with either one or two negative charges, depending on soil pH. Although other anions normally leach readily, phosphorus does not. Phosphorus reacts very strongly with iron, aluminum, and calcium in soil solution, with soil solids such as iron oxides, iron and aluminum hydroxides, and with lime. The strength of these reactions limits the movement of phosphorus.

Boron occurs as a leachable, uncharged molecule (boric acid, H_3BO_3), which reacts very weakly with soil clays.

2.2.4.2.2 *Factors Affecting Availability of Nutrients*

The availability of nutrients is influenced by the following factors:

- soil properties, particularly pH and texture

- the form of nutrients present in wastewater
- nutrient levels in the soil and soil/water solution

Soil Properties Affecting Availability of Nutrients

Soil pH greatly influences availability of nutrients. The influence of pH is discussed in Section 2.1.2.2.2. Soil texture is also an important soil property influencing nutrient availability. Not all soils are susceptible to the same nutrient deficiencies. Differences in soil texture will affect a soil's capacity to retain nutrients, as discussed further in Section 2.1.2.2.1

Table 2-8 shows some soil conditions that can lead to nutrient deficiencies.

Table 2-8. Soil factors that may lead to deficiencies of selected nutrients (NCDEQ, 2001).

Nutrient	Soil Factors Resulting in Deficiency
Nitrogen and Potassium	Excessive leaching on coarse-textured, low organic matter soils.
Phosphorus	Acid, low organic matter soils. Cold, wet soils such as occur during early spring. Newly cleared soils.
Sulfur	Excessive leaching on coarse-textured, low organic matter soils in areas where air pollution is low (minimal levels of SO_x).
Calcium and Magnesium	Excessive leaching on coarse-textured, low organic matter soils. Soils where large amounts of potassium have been applied.
Iron	Poorly drained soils. Low organic matter soils, high pH soils (pH > 7.0).
Zinc	Cold, wet soils low in organic matter and highly leached. High pH soils (pH > 7.0). Soils high in phosphorus.
Copper	Peat and muck soils. High pH, sandy soils.
Boron	Excessive leaching on coarse-textured, low organic matter soils. Soils with pH > 7.0.
Manganese	Excessive leaching on coarse-textured, low organic matter soils. Soils with pH > 6.5.
Molybdenum	Soils high in Fe oxides (high adsorption of molybdenum). Soils cropped for a long time.

Form of Nutrients Applied in Wastewater

Another factor that influences the plant availability of nutrients is the form in which nutrients are present in the wastewater applied to soil. Some nutrients in wastewater are largely present as organic compounds that must be broken down by soil microorganisms before plants can use the nutrients. Other nutrients are present as water-soluble salts that are immediately available for plant uptake.

Levels of Nutrient in the Soil and Soil Water Solution

There are three levels of nutrient availability (Figure 2-9):

- *Deficiency*: marked increases in yield occur with increasing amounts, or availability, of the nutrient, i.e., supply of the nutrient is inadequate and is limiting yield. An addition of the nutrient will increase yield.
- *Sufficiency*: the maximum economic yield has been reached and the nutrient is not limiting crop yield, so increasing the supply or availability of the nutrient has no effect on yield.
- *Toxicity*: further additions or availability of a nutrient beyond the sufficiency range causes marked decreases in yield and, eventually, no growth.

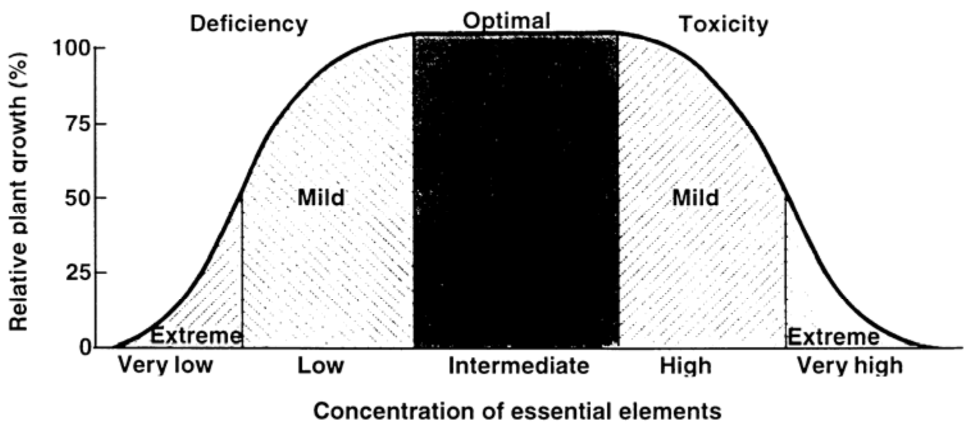

Figure 2-9. Relationship between plant growth and concentration in the soil solution of elements that are essential to plants. Nutrients must be released (or added) to the soil solution in the right amounts over time if normal plant growth is to occur (Brady 1990).

Symptoms of nutrient deficiency usually appear on the plant when one or more nutrients are in short supply. In many cases, a deficiency may occur because a nutrient is not in a plant-available form. Deficiency symptoms for specific elements are listed in Table 2-4.

Table 2-4. Key to nutrient disorders (NCDEQ, 2001).

Nutrient	Symptoms of Nutrient Deficiency
Nitrogen	General chlorosis (yellowing). Chlorosis progresses from light green to yellow. Entire plant becomes yellow under prolonged stress. Growth is immediately restricted and plants soon become spindly and drop older leaves.
Phosphorus	Leaves appear dull, dark green, blue green, or red-purple, especially on the underside, and especially at the midrib and vein. Petioles (the stalk that attaches the leaf to the stem) may also exhibit purpling. Restriction in growth may be noticed.
Potassium	Leaf margins tanned, scorched, or have necrotic (dead) spots (may be small black spots, which later coalesce). Margins become brown and cup downward. Growth is restricted and death (die back) may occur. Mild symptoms appear first on recently matured leaves, then become pronounced on older leaves, and, finally, on younger leaves. Symptoms may be more common late in the growing season due to translocation of potassium to developing storage organs.
Calcium	Growing points usually damaged or dead (die-back). Margins of leaves developing from the growing point are first to turn brown.
Magnesium	Marginal chlorosis or chlorotic blotches, which later merge. Leaves show yellow chlorotic inter-veinal tissue on some species, reddish purple progressing to necrosis on others. Younger leaves affected with continued stress. Chlorotic areas may become necrotic, brittle, and curl upward. Symptoms usually occur late in the growing season.
Sulfur	Leaves uniformly light green, followed by yellowing and poor, spindly growth. Uniform chlorosis does not occur.
Copper	Leaves wilt, become chlorotic, then necrotic. Wilting and necrosis are not dominant symptoms.
Iron	Distinct yellow or white areas appear between veins, and veins eventually become chlorotic. Symptoms are rare on mature leaves.
Manganese	Chlorosis is less marked near veins. Some mottling occurs in inter-veinal areas. Chlorotic areas eventually become brown, transparent, or necrotic. Symptoms may appear later on older leaves.
Zinc	Leaves may be abnormally small and necrotic. Internodes are shortened.
Boron	Young, expanding leaves may be necrotic or distorted followed by death of growing points. Internodes may be short, especially at shoot terminals. Stems may be rough, cracked, or split along the vascular bundles.

2.2.4.3 *Crop Constituent Uptake*

This section discusses crop constituent uptake including nutrients and salt, with emphasis on nitrogen. Salt, although not regarded as a nutrient except in relation to specific elements, is discussed here with application to crop uptake and salt balance in land treatment systems.

2.2.4.3.1 *Nutrient Uptake*

Nitrogen is often the limiting design factor, and several crops are heavy users of N. Nutrient uptake is directly related to dry matter yield, and crop stress will reduce yield. Nutrient loading should be balanced to avoid yield reductions from nutrient stress and environmental degradation from excess loading.

The relationship of nutrient availability and yield is non-linear. If the N loading is reduced to half of the expected uptake, it cannot be assumed that half the uptake will result. The actual yield and nutrient uptake will be a function of the initial soil reserve and resulting nutrient stress. Crop residue, straw, and other matter that is left in the field after harvest will eventually contribute nutrients back into the soil reserve. Soil and tissue analysis can help determine nutrient deficiency and proper nutrient loading.

The highest uptake of N, phosphorus, and potassium can generally be achieved by perennial grasses and legumes. It should be recognized that whereas legumes normally fix N from the air, they will preferentially take up N from the soil-water solution, if it is present. The potential for harvesting nutrients with annual crops is generally less than with perennials because annuals use only part of the available growing season for growth and active uptake. Crop nutrient uptake is discussed further in Section 4.4.2.3. Typical annual uptake rates of the major plant nutrients: N, phosphorus, and potassium, are listed in Table 7-30 for several crops.

The nutrient removal capacity of a crop is not a fixed characteristic but depends on the crop yield and the nutrient content of the plant at the time of harvest. Design estimates of harvest removals should be based on yield goals and nutrient compositions that local experience indicates can be achieved with good management on similar soils.

Alfalfa removes N and potassium in larger quantities and at a deeper rooting depth than most agricultural crops as shown in Table 2-5. Corn is an attractive crop because of its potentially high rate of economic return as grain or silage. The limited root biomass early in the season and the limited period of rapid nutrient uptake, however, can present problems for N removal. Prior to the fourth week, roots are too small for rapid uptake of N, and after the ninth week, plant uptake slows. During the rapid uptake period, however, corn removes N efficiently from percolating wastewater (D’Itri, 1982).

Table 2-5. **Typical effective rooting depth of crops by growth stages (Ashley, et al., 1997).**

Crop	Weeks After Emergence[1]	Stage of Development	Growth Stage Indicators	Total Depth of Effective Root Zone for Irrigation Water Management[2] (Feet)
Alfalfa Established stands				4.0
New stand	0 – 5 5 – 13 13 to dormancy	Vegetative Vegetative Vegetative		0.5 - 1.0 1.0 - 1.5 1.0 - 3.0
Cereal Grains, Spring	3	Haun Scale 1 to 3	Two leaves unfolded to four leaves unfolded (tillering)	0.5 - 1.0
	5	4 to 7	Five leaves unfolded to eight leaves unfolded	1.0 - 2.0
	6	8 to 11.6	Flag leaf through flowering	2.0 - 3.0
	8 to end of season	12 to 14.5	Milk development to soft dough	3.0 - 3.5
Cereal Grains, Winter		Haun Scale 1 to 3	Two leaves unfolded to four leaves unfolded (tillering)	0.5 - 1.0
		4 to 7	Five leaves unfolded to eight leaves unfolded	1.0 - 2.0
		8 to 11.6	Flag leaf through Flowering	2.0 - 3.0
		12 to 14.5	Milk development to Soft Dough	3.0 - 3.5
Corn, Field	2 6 8 11		3 leaf 12 leaf Silking Blister kernel	0.6 - 1.0 2.0 3.0 3.5
Dry Beans	2 to 3 4.5 to 5.5 6	V-4 V-10	4 leaf First Flower First Seed	0.8 - 1.0 1.5 2.0 - 2.5
Pasture				
Established				1.5 - 4.0
New stand	0 – 5	Vegetative Reproductive Maturity	 Flowering Mature seed	0.0- 0.5 0.5 - 1.5 1.5 - 3.0
Potato[3]	4	I Vegetative Growth	Emergence to 8 to 12 leaves	0.66 - 1.0
	6	II Tuber Initiation	Tubers begin to form at tips of stolens	1.0 - 1.5
	14.5	III Tuber Growth	Early bulking to mid bulking	1.5 - 2.0
	16.5 to 18	IV Maturation	Late bulking to maturity	2.0

The rate of N uptake by crops changes during the growing season and is a function of the rate of dry matter accumulation and the N content of the plant. For planning and nutrient balances, the rate of N uptake can be correlated to the rate of plant transpiration. Consequently, the pattern of N uptake is subject to many environmental and management variables and is crop specific. Examples of measured N uptake rates versus time are shown in Figure 2-10 for annual crops and perennial forage grasses.

The most common agricultural crops grown in Idaho for revenue using wastewater are corn (silage), alfalfa (silage, hay, or pasture), forage grass (silage, hay or pasture), and grains. However, any crop, including food crops, may be grown with food processing wastewater because there is little concern with microbial or viral contamination. In areas with a long growing season, selection of a double crop is an excellent means of increasing the revenue potential as well as the annual consumptive water use and nitrogen uptake of the crop system. Double crop combinations that are commonly used include summer crops of short season varieties of silage corn or winter crops of barley, oats, wheat, or annual forage grass as a winter crop.

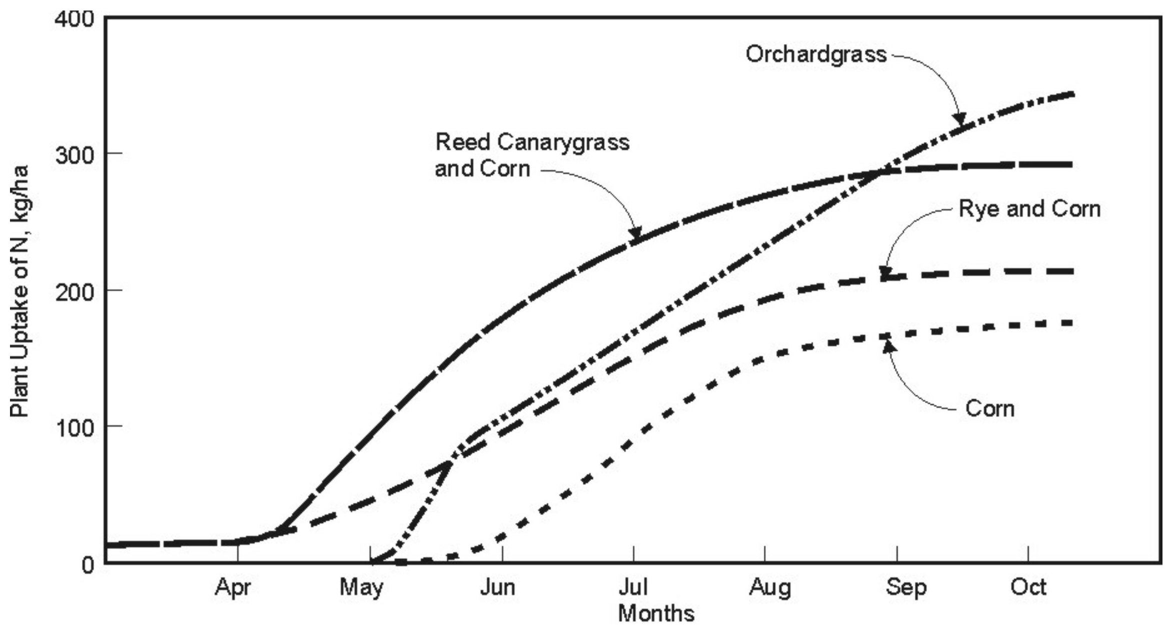

Figure 2-10. Nitrogen uptake for annual and perennial crops (EPA, 2006).

Some forage crops can have even higher N uptakes than those in standard tables. The nitrogen crop uptake measured for turfgrasses in Tucson (common bermudagrass overseeded with winter ryegrass) is 525 lb/acre-yr (Pepper, 1981). “Luxury consumption” may occur in the presence of surplus soil N, and result in higher than normal crop uptake rates.

Essentially all N absorbed from the soil by plant roots is in the inorganic form of either nitrate (NO_3^-) or ammonium (NH_4^+). Generally young plants absorb ammonium more readily than nitrate; however as the plant ages the reverse is true. Soil conditions that promote plant growth (warm and well aerated) also promote the microbial conversion of ammonium to nitrate. As a result, nitrate is generally more abundant when growing conditions are most favorable. Once inside the plant, the majority of the N is incorporated into amino acids, the building blocks of protein. Protein is approximately 16 percent N by weight. N makes up from one to four percent of the plants harvested dry weight.

2.2.4.3.2 *Salt Uptake*

Along with N, crops also take-up other dissolved minerals including phosphorus, potassium, calcium, magnesium, and sulfur. These dissolved minerals can be measured as the portion (typically 50 – 70 percent) of the ash content of the plant. The ash content is approximately 10 percent of the dry mass of the plant, so increased yield directly correlates to salt uptake. Ash content of cereal crops can be found in Table A-11 of Warren and Martin (1963). Ash content of field crops can be found in Table A-2 of Martin et al. (1976).

Table 2-6 shows actual field results of salt removal from various crops that were grown with wastewater.

Table 2-6. Yield and salt removal of various crops (CLFP, 2007).

	Average Yield dry tons/acre	Salts Removed lbs/acre	Ash Percentage
Alfalfa[a]	6.6	2093	16%
Barley[a]	3.9	759	10%
Field Corn[b] **(Grain plus stover)**	11.7	1750	7.5%
Winter wheat[b] **(Grain plus straw)**	5.2	1321	13%
Tall Fescue[a]	8.4	2083	12%

Source: Tim Ruby, Del Monte Foods Company
a) Process water spray irrigation site located outside Boise, ID, two year average
b) Process water surface irrigation site, Kingsburg, CA, one year.
Note: For data utilized to create this summary table, see CLFP (2007) Appendix H.

The uptake of the constituents that make up TDS is dependent on the crop and the crop yield. Data in Table 2-12 can be used to conservatively estimate the uptake of selected constituents that are applied in wastewater. The ‘total uptake’ in Table 2-12 underestimates the total mineral removal because certain constituents (e.g. sodium and chloride) are not included. The actual or expected yield can be used to adjust the mineral removal values in Table 2-6 when doing salt uptake calculations.

Table 2-12. Constituent uptake estimates for crops (from Mitchell, 1999).

Crop	Yield Per Acre (tons)	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Totals
		lb/acre											
Alfalfa Hay	8	415	41	333	151	36	26	0.43	0.11	1.67	0.45	0.3	1126
Bermuda grass Hay	8	400	40	286	48	32	0.13	0.02	1.2	0.64	0.48	951	951
Corn, Grain	5.04	170	31	40	15	16	14	0.12	0.06	0.15	0.09	0.16	334
Corn Stover	4	70	13	159	27	34	16	0.05	0.05	0.9	1.5	0.3	372
Corn Silage	16	160	29	133	28	33	20	0.11	0.07	0.7	1.06	0.3	470
Oats, Grain	26	80	11	17	3	5	8	—	0.04	0.8	0.15	0.06	142
Oats, Straw	3.5	35	7	104	10	15	11	0.05	0.04	0.15	0.15	0.36	212
Sorghum-Sudan Hay	4	160	27	193	30	24	23	—	—	—	—	—	531
Tomatoes-Fruit	15	50	5	90	3	14	20		0.07	1.3	0.13	0.16	209
Tomatoes-Vines	—	40	6	50	—	—	—	—	—	—	—	—	113
Wheat, grain	2.4	92	19	22	2	12	5	0.06	0.05	0.45	0.14	0.21	183
Wheat, straw	3	42	4	195	9	12	15	0.02	0.02	1.95	.24	0.08	225

Notes:

Data obtained from Auburn University, Alabama Cooperative Extension System and combines data from The Fertilizer Institute, Phosphate and Potash Institute, and independent research resources (http://www.aces.edu/pubs/docs/A/ANR-0449/)

Yields are for high-yielding Alabama crops. Values reported in this table may differ from values from other sources. Healthy, high-yielding crops can vary considerably in the nutrient concentration in the grain, fruit, leaves, stems, and pods. Plant “uptake” is also higher than crop “removal.” Nutrients not actually removed from the land are returned to the soil in organic residues. Crop removal should be adjusted in proportion to the actual yield.

2.2.4.4 *Nutrient Management*

When plant nutrients are applied to soils as wastewater, wastewater residuals, animal manure, or commercial fertilizers, five things can happen. Nutrients can either:

- be taken up by the plants.
- remain in the soil.
- be lost by leaching through the soil profile or through denitrification or volatilization as gases losses.
- If fertilizers or wastes are left on the soil surface, runoff water may carry nutrients away in solution or as part of eroded sediments.

To make efficient use of nutrients, and minimize impacts to the environment, careful *nutrient management planning* should be done to determine appropriate loading rates for site- and crop-specific circumstances. This is discussed further in Section 4.2.2.3.

2.3 Sociological Factors and Land Use

Sociological factors must be taken into account when evaluating suitability of wastewater land application proposals. Planning and zoning is discussed as well as considerations relating especially to nuisance conditions.

2.3.1 Planning and Zoning Requirements

Chapter 65, Title 67, Idaho Code grants authority for comprehensive land use planning to local government. Contact the local city or county Planning and Zoning (P&Z) authority for zoning permits, conditional use permits and building permits; flood plain and storm water run-off requirements; and other types of planning requirements such as landscaping requirements for both new, expansions or remodels to existing facilities.

Some P&Z departments may require a conditional use permit for the wastewater-land application system separate from the facility's zoning permit for the site. Some P&Z authorities may also act as the coordinator for approvals coming in from various agency inspectors on such issues as plumbing, electrical and fire codes.

An evaluation of the surrounding land uses should take place as part of determining the acceptability of the site by the community. The present land use should be evaluated in site selection. The planned use of the site should not conflict with the present or planned uses of adjacent property. Land uses that need to be considered in site evaluation include proximity of municipal wells and wells for domestic use, proximity of homes, and proximity of other installations and industry that have the potential for impacts on ground water or air quality such as landfills.

Direction from potential conflicting land uses is an important land use consideration. It may not be suitable for a wastewater land application facility to be located upwind from an urban area, or up gradient of a municipal well. See both Section 6.5 (*Buffer Zones and Distances*) and 6.6 (*Protection of Domestic and Public Well Water Supplies*) for additional information. See also DEQ Policy Memorandum PMOO-6, *Policy for Responding to Odor Complaints*:

http://www.deq.state.id.us/about/policies/pm00_6.cfm

Local officials and the public should be included as part of site selection considerations. Realizing the possible health and nuisance impacts a land-applied wastewater facility can create, public awareness may help determine what may or may not be acceptable. Trying to correct a problem after the fact can be very time consuming and costly.

2.3.2 Nuisance Conditions

Reuse permittees should avoid nuisance conditions during land treatment operations. The most effective way to do this is to prevent them from occurring.

2.3.2.1 *Nuisance Prevention*

The permittee can initiate its own nuisance prevention program for odors, vectors, insects and other nuisance conditions through:

- Equipment design, i.e. designing drainage of all transfer lines to prevent wastewater turning anaerobic.
- Follow-through on operation and maintenance that includes management of probable or potential nuisance conditions.
- Proactive company outreach to adjacent property owners and/or immediate community to inform them about the facility and wastewater-land application system. Effective outreach may consist of, offering a tour of the facility, or asking the community for its input to jointly resolve a potential nuisance condition before it becomes a reality. One real life solution to an ongoing nuisance situation by a community occurred after an industry officer was elected to city council and saw their company in the eyes of the whole community.

2.3.2.2 *Authorities for Nuisance Regulation*

In addition to what the permittee might choose to voluntarily do, Idaho law provides direction in regard to nuisance conditions. The Idaho State Constitution and Idaho Code recognize four types of nuisance conditions: private, public, general and public health. Prevention and resolution of nuisance conditions by law are based on:

- *Local (city/county) laws or ordinances* regarding general, public, or public health based nuisances.

  This means that any county law(s) or ordinance(s) pertaining to nuisances that exist may become a condition of the local P&Z permit or building permit issued to a reuse facility. The local city or county should direct any resolution efforts on city/county laws or ordinances.

- *The Idaho State Constitution and Idaho Code*. The constitution and code provides cities and counties with the authority to take necessary steps to protect the public health, safety and general welfare of citizens within their jurisdictions. As such, abatement of general or public nuisances may also be resolved by a local city or county.

  Idaho Code distinguishes between public "health" nuisances and general or public nuisances, granting authority to the district health departments to abate public "health" nuisances.

- *Compliance with Permit Conditions.* Prevention and resolution of nuisance conditions may be a condition of a license or permit. Compliance with required permit conditions is addressed by the agency with permitting authority such as the Department of Water Resources for drilling a well or DEQ for an air quality permit or a reuse permit. One example of language used to address potential nuisance conditions in a reuse permit follows:

"Wastewater must not create a public health hazard or nuisance condition as stated in IDAPA 58.01.16.600.03. In order to prevent public health hazards and nuisance conditions the permittee shall:

a. Apply wastewater as evenly as practicable to the entire treatment area;
b. Prevent organic solids (contained in the wastewater) from accumulating on the ground surface to the point where the solids putrefy or support vectors or insects; and
c. Prevent wastewater from ponding in the fields to the point where the ponded wastewater putrefies or supports vectors or insects."

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2.5 Supplementary Material

2.5.1 Typical Idaho Soil Chemistry Values – Stukenholtz Laboratory, Inc.

Stukenholtz Laboratory, Inc. (4/26/2007)
Addison Avenue East ● Box 353 ● Twin Falls, Idaho 83303-0353
PHONE (208) 734-3050 ● 800-759-3050 ● FAX (208) 734-3919

	LOW	MEDIUM	HIGH	VERY HIGH
pH	4.5–5.5	5.6–7.0	7.1–8.3	8.4+
CEC, meq/100g	0–10	9–18	17–24	25+
Sodium, meq/100g	0–0.5	0.6–1.5	1.6–4.0	4.1+
Salts, mmhos/cm	0–1.0	1.1–2.5	2.6–5.0	5.1+
Organic Matter, %	0–1.0	1.1–1.7	1.8–3.0	3.1+
Lime, %	0–1.0	1.1–4.0	4.1–9.0	9.1+
N-Nitrate, ppm	0–5	6–20	21–40	41+
P Phosphorus, ppm	0–15	15-30	30-50	51+
K Potassium, ppm	0–115	115–250	250–500	500+
Ca Calcium, meq/100g	0-5.0	5.1-10.0	10.1-15.0	15.1+
Mg Magnesium, meq/100g	0–1.0	1.1–3.0	3.1–5.0	5.1+
S Sulfur, ppm	0–8	9–18	19–40	41+
Zn Zinc, ppm	0–0.8	0.9–1.8	1.9–3.0	3.1+
Fe Iron, ppm	0–3.0	3.1–6.0	6.1–15.0	15.1+
Mn Manganese, ppm	0–3.0	3.1–6.0	6.1–15.0	15.1+
Cu Copper, ppm	0–0.5	0.6–1.2	1.3–3.0	3.1+
B Boron, ppm	0–0.6	0.7–1.1	1.2–3.0	3.1+

*These soil test levels help interpret soil tests but are not designed for making recommendations. These nutrient levels are approximate and will vary according to the crop and yield goal. Nutrient levels and resultant recommendations will also vary according to the balance between nutrients such as P/Zn, P/Fe, K/Mg, Zn/Fe and others.

SOIL TEXTURE (Approx.)	CEC (meq/100g)
Clay	36+
Clay Loam	22–36
Silt Loam	16–24
Sandy Loam	10–18
Loamy Sand	5–12
Sand	0–6

2.5.2 Typical Idaho Soil Chemistry Values – Western Laboratories, Inc.

Soil Chemistry Data from Typical Agricultural Soils
Western Laboratories, P.O. Box 400, Parma ID 83660

	VERY LOW	**LOW**	**MEDIUM**	**HIGH**	**VERY HIGH**
Organic Matter[1], %	0.0 to 0.9	1.0 to 1.5	1.6 to 2.5	2.6 to 4.9	above 5.0
NO3-N[2], ppm	0-5	6-10	11-25	26-40	41+
Phosphorus[3], ppm	1-4	5-11	12-25	26-45	45+
Potassium-K[4], ppm	0-100	101-200	201-450	451-750	750+
Calcium, ppm	0-900	901-1500	1501-4000	4001-5000	5000+
Sodium, ppm	0-30	31-60	61-175	176-450	450+
Free Lime[5], %	0.0-0.25	0.25-0.5	0.6-2.9	3.0-8.0	8.1+

1) Walkley-Black Titration Method
2) Buffered Extraction Method
3) Sodium Bicarbonate Method
4) Ammonium Acetate Method
5) 1N HCL Method

Organic Matter Release of Nitrogen/Acre/Year **% OM x Factor = Pounds Nitrogen/Ac/Yr** **Factors**	
60	S.E. Washington-N.E. Oregon
55	Winnemucca, Nevada
50	E. Oregon-S.W. Idaho
40	Magic Valley, Idaho
35	E. Idaho-N. Utah
30	W. Wyoming

Element	**Low to Deficient**	**Adequate**	**Excessive to Toxic**
SO_4-S (sulfate water soluble)	less than 10ppm	10 to 30 ppm	—
Zn (zinc by DTPA-TEA)	less than 0.8 ppm	0.9 to 4.0 ppm	15+ ppm
Mn (manganese by DTPA-TEA)	less than 2.0 ppm	3 to 7 ppm	150+ ppm
Cu (copper by DTPA-TEA)	less than 0.3 ppm	0.7 to 4.0 ppm	20+ ppm
Fe (iron by DTPA-TEA)	less than 5.0 ppm	5 to 10 ppm	—
B (boron by hot water soluble)	less than 0.5 ppm	0.5 to 2.0 ppm	3 + ppm

% Na of the CEC Based on Different Sodium Concentrations and Cation Exchange Capacities CEC in meq/100g of Soil								
Soil Sodium in ppm-Na	8	10	12	14	16	18	20	22
	% Sodium of the CEC							
100	5.4	4.3	3.6	3.1	2.7	2.4	2.2	2.0
200	10.9	8.7	7.3	6.2	5.4	4.8	4.4	4.0
300	16.3	13.0	10.8	9.3	8.1	7.2	6.5	5.9
400	21.8	17.4	14.5	12.4	10.9	9.7	8.7	7.9
500	27.1	21.7	18.1	15.5	13.6	12.1	10.9	9.9
600	32.6	26.1	21.8	18.6	16.3	14.5	13.1	11.9
700	38.0	30.4	25.3	21.7	19.0	16.9	15.2	13.8
800	43.5	34.8	29.0	24.9	21.8	19.3	17.4	15.8
900	48.9	39.1	32.6	28.0	24.5	21.7	19.6	17.8
1000	54.4	43.5	36.3	31.1	27.2	24.2	21.8	19.8
1500	81.5	65.2	54.3	46.6	40.8	36.2	32.6	29.6
2000	108.8	87.0	72.4	62.1	54.4	48.3	43.5	39.5
2500	135.9	108.7	90.6	77.6	67.9	60.4	54.4	49.4
3000	163.0	130.4	108.7	93.1	81.5	72.4	65.2	59.3
3500	190.3	152.2	126.8	108.7	95.1	84.6	76.1	69.2
4000	217.4	173.9	144.9	124.2	108.7	96.6	87.0	79.0

Crop Tolerance for Percent Na of the CEC			
0 to 5%	5 to 10%	10 to 15%	15 + %
Beans **Strawberries** **Carrot Seed** **Radish Seed** **Onions** **Lettuce Seed** **Fruit Trees** **Potatoes** **Hops** **Orchard Grass** **Cabbage Seed** **Most Clovers** **Celery** **Tomatoes** **Peppermint** **Peas**	Wheat Oats Spearmint Alfalfa Turnip Seed Sweet Corn Field Corn Pasture Cotton	Crested Wheat Fescue Perennial Rye Sugar Beets Tall Wheat Birdsfoot Trefoil	Barley Salt Grass

2.5.3 Hydraulic Data for Hydrogeological Settings in Idaho

Table 2-13. Hydrologic Data and References for the Basic I Calculations, Idaho Wellhead Protection Program (DEQ, 1997)

Hydrogeologic Setting	Transmissivity (T)	Aquifer Thickness (b)	Hydraulic Conductivity (K)	Hydraulic Gradient (I)	Effective Porosity (N_e)	Values Used for Basic I Calculations
East Snake River Plain Basalts	650,000 - 67,240,000 gpd/ft Ref: (12,21,25, 26) 400,000 gpd/ft (Avg) Ref: (18)	Several 100 to 1,000 ft Ref: (21) 500 - 4,000 ft Ref: (20)	3,740 -37,400 gpd/ft' Min = 74.8 gpd/ft^2 Max = 74,800 gpd/ft^2 Ref: (2, 23)	.001 - .006 Ref: (23) Gradient as low as .0003 exist. Ret: (26)	.11 - .19 Ref: (3, 17)	T = 400,000 gpd/ft b = 600 ft. I = 0.004 N_e 0.15
Columbia River Basalts	20,196 - 2,01 9,600 gpd/ft Ref: (1) 40,000 gpd/ft (Avg) Ref: (18)	20 - 800 ft. Ref: (1, 8)		.0002 Ref: (24)	.004 - .19 Ref: (4) 0.0002 Ref: (13)	T= 40,000 gpd/ft b = 400 ft I = 0.0002 N_e=0.1
Rathdrum Prairie	2,019,600 - 97,240,000 gpd/ft Ref: (10,16)	500 -1,000 ft Ref: (10, 6) 250 - 400 ft Ref: (27)	3,740 - 164,560 gpd/ft^2 Ref: (10, 16)	.0004 - .005 Ref: (10, 16) .0005 - .009 Ref: (27)	.25 - .30 Ref: (10)	See Rathdrum Prairies Aquifer delineation in Chapter 3.
Unconsolidated Alluvium	200,000 gpd/ft. (Avg) Ref: (18)	100 ft. estimated	74.8 - 2,992 gpd/ft^2 Ref: (10, 16)	.003 - .02 Ref: (5, 6, 7)	.20 - .35 Ref: (11)	T= 200,000 gpd/ft b= 100 ft. 1= 0.01 N_e = 0.3
Mixed Volcanic and Sedimentary Rocks - Primarily Sedimentary Rocks (Example: Boise/ Nampa area)	6,732 - 160,820 gpd/ft Ref: (29) 30,000 gpd/ft (Avg) Ref: (18)	500 - 4,000 ft Ref: (29) 500 - 1,000 ft Ref: (33)	74.8 -748 gpd/ft^2 upper 500 ft Ref: (29)	.002 - .004 Ref: (22)	.10 - .30 Ref: (11)	T = 30,000 gpd/ft b = 800 ft I = 0.003 N_e = 0.2
Mixed Volcanic and Sedimentary Rocks - Primarily Volcanic Rocks (Example: Mtn Home)	374,000 gpd/ft Ref: (35)	500 -600 ft Ref: (30)		.012 - .015 Ref: (22)	.11 - .19 Ref: (11)	T = 400,000 gpd/ft b = 600 ft I = 0.01 N_e = 0.2

2.5.4 Well Test Data/ Transmissivity Values for Wells in Idaho

Table 2-14. Idaho Department of Water Resources Energy Data (DEQ, 1997)

Aquifer	City	Pumpid	Testdat	SWL	PWL	PWL-SWL	Flow	SC	Est R(')	Est R(")	T(art.)
Alluv	Challis	West Well #2	19880802	317.0	487.5	170.5	522	3.1	0.83	10	4690
Alluv	Rockland	25-hp Vertical Turbin	19890906	111.0	177.0	66.0	245	3.7	0.67	8	5970
Alluv	New Meadows	Submersible	19890901	19.0	78.0	59.0	253	4.3	0.67	8	6980
Alluv	Rockland	25-hp Submersible	19890906	111.0	177.0	66.0	322	4.9	0.67	8	8020
Alluv	Arimo	#1	19890717	30.0	56.0	26.0	346	13.3	0.67	8	23500
Alluv	Ketchum	Well #2	19880929	18.0	39.3	21.3	347	16.3	0.67	8	29100
Alluv	Bancroft	City Pump	19890719	95.0	104.0	9.0	188	20.9	0.67	8	38000
Alluv	Mackay	30-hp Submersible	19890913	11.0	27.0	16.0	420	26.2	0.83	10	47100
Alluv	Mackay	Well Pump #2	19910819	11.7	22.7	11.0	290	26.4	0.67	8	48700
Alluv	Tetonia	Park Well	19891107	101.0	110.0	9.0	395	43.9	0.83	10	81600
Alluv	Riggins	Well #2-new Pump	19900612	50.0	57.0	7.0	388	55.4	0.83	10	104000
Alluv	Grace	Well Pump	19890719	161.0	172.0	11.0	660	60.0	1.00	12	111000
Alluv	Bancroft	Railroad Pump	19890719	106.0	108.0	2.0	115	57.4	0.50	6	115000
Alluv	Ketchum	Well #1	19880929	59.3	75.6	16.3	1054	64.7	1.10	13.25	118000
Alluv	Malad	Five Points Well	19890718	78.0	82.0	4.0	263	65.7	0.67	8	129000
Alluv	Dayton	Park Well	19890718	52.0	56.0	4.0	333	83.3	0.83	10	161000
Alluv	Arco	Park Pump	19891016	125.0	135.0	10.0	906	90.6	0.00	12	172000
Alluv	Sun Valley	Pump #8	19880927	19.0	29.9	10.9	1139	104.5	1.10	13.25	198000
Alluv	Pocatello	Well #32	19880608	59.2	71.5	12.3	1604	130.4	1.10	13.25	251000
Alluv	Pocatello	Well #29	19880607	70.8	87.9	17.1	2493	145.8	1.27	15.25	277000
Alluv	Pocatello	Well #2	19880607	34.9	43.5	8.6	1265	147.0	1.10	13.25	285000
Alluv	Sun Valley	Pump #5	19880927	12.5	16.0	3.5	787	224.9	1.00	12	452000
Alluv	Pocatello	Well #27	19880607	63.3	69.2	5.9	1623	275.2	1.10	13.25	554000
Alluv	Sun Valley	Pump #7	19880927	20.0	23.5	3.5	1039	296.9	1.10	13.25	601000
Alluv	Pocatello	Well #18	19880608	66.2	72.6	6.4	2020	315.5	1.27	15.25	630000
Alluv	Pocatello	Pip Well	19880608	69.6	72.6	3.0	1188	395.8	1.10	13.25	815000
Alluv	Malad	Spring Creek Well/5	19890718	84.0	85.0	1.0	413	413.2	0.83	10	881000
Alluv	Pocatello	Well #16	19880607	46.7	49.5	2.8	2267	809.8	1.27	15.25	1710000
Alluv	Pocatello	Well #28	19880607	34.6	35.9	1.3	1755	1349.8	1.27	15.25	2930000
Alluv	Pocatello	Well #31	19880608	62.2	64.1	1.9	2937	1546.0	1.27	15.25	3380000
Alluv	Pocatello	Well #12	19880607	43.3	44.7	1.4	2812	2008.2	1.27	15.25	4460000
Alluv	Pocatello	Well #10	19880607	52.4	53.9	1.5	3419	2279.5	1.60	19.25	4970000
Alluv	Pocatello	Well #21	19880607	79.6	80.1	0.5	1581	3161.8	1.10	13.25	7300000
Alluv	Pocatello	Cree Well	19880606	35.4	35.5	0.1	388	3877.0	0.83	10	9320000
Alluv	Pocatello	Well #22	19880607	87.5	87.6	0.1	871	8714.0	1.10	13.25	2E+07
CR Basalt	Kooskia	Well #3	19881004	101.0	350.0	249.0	246	1.0	0.67	8	1420
CR Basalt	Council	Pump #1	19870619	277.2	374.2	97.0	337	3.5	0.83	10	5380
CR Basalt	Moscow	Cemetary Well	19880822	170.4	228.2	57.8	467	8.1	0.83	10	13300
CR Basalt	Moscow	Cemetary Well	19880822	170.4	228.2	57.8	708	12.3	1.00	12	20300
CR Basalt	Council	Pump #2	19870619	50.0	79.2	29.2	356	12.2	0.83	10	20700
CR Basalt	Kooskia	Well #1	19881004	43.5	64.0	20.5	248	12.1	0.67	8	21200
CR Basalt	Kooskia	Well #2	19881004	45.5	66.0	20.5	255	12.4	0.67	8	21800
CR Basalt	Univ of Idaho	Well #4	19880824	195.0	295.4	100.4	1901	18.9	1.27	15.25	31300
CR Basalt	Moscow	Well #8	19880822	370.2	404.9	34.7	980	28.2	1.10	13.25	49000
CR Basalt	Moscow	Well #6	19880823	344.9	376.1	31.2	1339	42.9	1.10	13.25	76700
CR Basalt	Moscow	Well #2	19880822	138.7	153.8	15.1	864	57.2	1.10	13.25	104000
CR Basalt	Univ of Idaho	Well #3	19880824	297.0	301.0	4.0	1812	453.1	1.27	15.25	924000
CR Basalt	Lewiston	Well #5	19880713	150.6	152.0	1.4	1180	842.6	1.10	13.25	1810000
E. Snake	Hollister	Well Pump	19890816	158.0	189.0	31.0	197	6.4	0.50	6	11100
E. Snake	Roberts	Well #2	19880626	23.9	47.1	23.2	407	17.6	0.83	10	30600
E. Snake	Filer	Pump #5	19870603	42.4	60.4	18.0	345	19.2	0.83	10	33700
E. Snake	Teton	Well #2	19891019	91.5	100.0	8.5	252	29.6	0.67	8	55300

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- MVS-Sed = Mixed Volcanic and Sedimentary Rocks, Primarily Sedimentary Rocks
- Rathdrum = Rathdrum Prairie Aquifer

City = City location of the well
Pumpid = Well identification
SWL = Static water level, in feet
PWL = Pumping water level, in feet
PWL-SWL = Difference between PWL and SWL, in feet
Flow = Calculated flow rate, in gallons per minute (gpm)
SC = Specific capacity, in gallons per minute per foot of drawdown
Est R('); Est R(") = Estimated radius of the well in feet; inches

Aquifer	City	Pumpid	Testdat	SWL	PWL	PWL-SWL	Flow	SC	Est R(')	Est R(")	T(art.)
E. Snake	Roberts	Well #3	19880626	64.4	87.6	23.2	727	31.3	1.00	12	55500
E. Snake	Shelley	Pump #4	19880525	103.0	144.6	41.6	1422	34.2	1.10	13.25	60200
E. Snake	Shelley	Pump #1	19880525	107.7	125.0	17.3	576	33.3	0.83	10	60800
E. Snake	Burley	#1	19890804	205.0	228.0	23.0	821	35.7	1.00	12	63800
E. Snake	Ashton	#1	19890912	28.0	44.0	16.0	900	56.3	1.00	12	103000
E. Snake	Aberdeen	Well #2	19870604	25.0	33.0	8.0	634	79.2	0.83	10	153000
E. Snake	Ammon	Well #6	19880524	86.0	102.2	16.2	1340	82.7	1.10	13.25	154000
E. Snake	Idaho Falls	Well #15 Main	19870626	106.0	124.0	18.0	2093	116.3	1.27	15.25	218000
E. Snake	Ririe	Pump #2	19871029	34.0	35.0	1.0	106	106.3	0.50	6	221000
E. Snake	Iona	Tank Pump	19870625	207.0	216.5	9.5	1312	138.1	1.27	15.25	261000
E. Snake	Rigby	Shop Well	19891018	15.0	22.0	7.0	1047	149.5	1.10	13.25	290000
E. Snake	Ammon	Well #7	19880524	65.0	74.4	9.4	1410	150.0	1.10	13.25	291000
E. Snake	Burley	#4	19890804	222.0	230.0	8.0	1227	153.3	1.17	14	295000
E. Snake	Rupert	Well #1	19890801	185.0	190.0	5.0	833	166.7	1.10	13.25	325000
E. Snake	Idaho Falls	Well #11 1435 RPM	19870624	195.0	208.0	13.0	3587	276.0	1.94	23.25	518000
E. Snake	Ririe	Pump #3	19871029	40.0	41.0	1.0	251	251.0	0.67	8	533000
E. Snake	Idaho Falls	Well #4 Main	19870623	155.0	172.0	17.0	4942	290.7	1.94	23.25	547000
E. Snake	Rigby	Well Pump #2	19891018	15.0	22.0	7.0	2441	348.8	1.27	15.25	700000
E. Snake	Idaho Falls	Well #11 1610 RPM	19870624	195.0	208.0	13.0	4861	373.9	1.10	13.25	767000
E. Snake	Dubois	Well #1	19891020	355.0	356.0	1.0	404	403.6	0.83	10	860000
E. Snake	Rigby	Harwood #3	19891018	15.0	16.0	1.0	420	419.9	0.83	10	896000
E. Snake	Dubois	Well #3	19891020	355.0	356.0	1.0	613	613.1	0.83	10	1330000
E. Snake	Shelley	Pump #3	19880525	92.6	95.7	3.1	1995	643.4	1.27	15.25	1340000
E. Snake	Shoshone	Pump #3	19871029	210.8	212.1	1.3	824	633.9	1.00	12	1350000
E. Snake	Rexburg	Well #5	19891017	324.0	327.0	3.0	2060	686.7	1.27	15.25	1430000
E. Snake	Rupert	Well #2'	19890801	185.0	187.0	2.0	1681	840.3	1.10	13.25	1800000
E. Snake	Rexburg	Well #1	19891017	208.0	210.0	2.0	2188	1093.8	1.27	15.25	2350000
E. Snake	Rexburg	Well #6	19891017	208.0	210.0	2.0	2246	1122.8	1.27	15.25	2410000
E. Snake	Jerome	Well Pump #2	19890816	284.8	285.8	1.0	1396	1396.4	1.27	15.25	3040000
E. Snake	Idaho Falls	Well #2 Main	19870622	167.0	169.0	2.0	2803	1401.3	1.27	15.25	3050000
E. Snake	Jerome	Well Pump #1	19890816	284.8	285.8	1.0	1493	1492.9	1.10	13.25	3310000
E. Snake	Idaho Falls	Well #3	19870626	165.0	166.0	1.0	4719	4718.6	1.94	23.25	1E+07
MVS-VS	Kuna	Process Pump	19880815	240.0	310.5	70.5	223	3.2	0.67	8	5030
MVS-VS	Kuna	Well #2	19880815	93.7	112.3	18.6	580	31.2	1.00	12	55300
MVS-VS	Kuna	Well #3	19880815	84.6	115.9	31.3	1801	57.5	1.27	15.25	102000
MVS-VS	Grandview	Pump #2	19880830	82.7	85.4	2.7	226	83.5	0.67	8	166000
MVS-VS	Grandview	Pump #1	19880830	79.7	82.1	2.4	246	102.5	0.67	8	206000
MVS-SED	Homedale	Well #2	19880602	44.2	222	178.1	198	1.1	0.5	6	1700
MVS-SED	Homedale	Old City Hall Well	19880602	41.8	216.0	174.2	206	1.2	0.67	8	1730
MVS-SED	Eagle	#2 Submersible	19910520	50.9	133.8	82.9	266	3.2	0.67	8	5100
MVS-SED	Nampa	Well #10	19880518	17.0	191.0	174.0	605	3.5	0.83	10	5380
MVS-SED	Caldwell	Well #9 1670 RPM	19880816	50.5	233.2	182.7	779	4.3	1.00	12	6510
MVS-SED	Caldwell	Well #13	19880816	10.7	149.5	138.8	772	5.6	1.00	12	8680
MVS-SED	Caldwell	Well #10	19880816	11.6	145.0	133.4	751	5.6	1.00	12	8790
MVS-SED	Homedale	Park Well	19880602	4.6	42.5	37.9	207	5.5	0.67	8	9050
MVS-SED	Nampa	Well #8	19880517	56.1	171.2	115.1	862	7.5	1.10	13.25	11700
MVS-SED	Caldwell	Well #7 1870 RPM	19880816	6.0	110.0	104.0	889	8.5	1.00	12	13700
MVS-SED	Parma	Well #7	19880826	24.5	138.4	113.9	1033	9.1	1.10	13.25	14400
MVS-SED	Caldwell	Well #11	19880816	10.6	112.2	101.6	986	9.7	1.00	12	15800
MVS-SED	Wilder	Pump #2	19880823	98.0	132.0	34.0	337	9.9	0.83	10	16600
MVS-SED	Caldwell	Well #6	19880816	9.5	90.0	80.5	864	10.7	1.00	12	17600

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SC = Specific capacity, in gallons per minute per foot of drawdown
Est R('); Est R(") = Estimated radius of the well in feet; inches
T(art.) = Transmissivity, in gallons per day per foot (gpd/ft) (Uses confined aquifer storage coefficient)

Idaho Wellhead Protection Plan

Aquifer	City	Pumpid	Testdat	SWL	PWL	PWL-SWL	Flow	SC	Est R(')	Est R(")	T(art.)
MVS-SED	Caldwell	Well #14	19880817	34.9	85.8	50.9	679	13.3	0.83	10	22800
MVS-SED	Garden City	#1	19890726	132.5	160.0	27.5	368	13.4	0.83	10	22900
MVS-SED	Caldwell	Well #8 1200 RPM	19880817	9.4	39.4	30.0	566	18.9	1.00	12	32200
MVS-SED	Notus	#2	19890524	30.0	55.0	25.0	490	19.6	0.83	10	34500
MVS-SED	Nampa	Colorado	19880619	9.5	45.0	35.5	774	21.8	1.00	12	37700
MVS-SED	Nampa	Well #7	19880518	11.3	41.8	30.5	823	27.0	1.10	13.25	46700
MVS-SED	Nampa	Well #9 1280 RPM	19880518	1.0	18.5	17.5	458	26.2	0.83	10	47000
MVS-SED	Eagle	#1 Submersible	19910520	40.0	59.0	19.0	539	28.4	0.83	10	51200
MVS-SED	Garden City	#5 (Variable Speed)	19890726	22.0	36.0	14.0	490	35.0	0.83	10	64100
MVS-SED	Middleton	Pump #4	19890808	86.0	135.0	49.0	1903	38.8	1.27	15.25	87600
MVS-SED	Nampa	Well #6	19880517	32.0	49.0	17.0	830	48.8	1.10	13.25	88100
MVS-SED	Caldwell	Well #4	19880817	74.0	80.3	6.3	295	46.9	0.67	8	89900
MVS-SED	Garden City	#43	19890727	15.0	35.0	20.0	1219	60.9	1.10	13.25	111000
MVS-SED	Nampa	Holly	19880619	17.3	27.5	10.2	695	68.1	1.00	12	127000
MVS-SED	Eagle	#3 Submersible	19910520	65.5	69.2	3.7	259	69.9	0.67	8	137000
MVS-SED	Nampa	19th Ave. N.	19880619	3.1	10.0	6.9	591	85.6	1.00	12	162000
MVS-SED	Nampa	Venice	19880519	16.8	22.0	5.2	462	88.8	0.83	10	172000
MVS-SED	Nampa	Juniper Square	19880619	23.0	24.0	1.0	137	137.1	0.50	6	290000
Rathdrum	Coeur d'Alene	Atlas Road Well	19870804	241.0	245.0	4.0	1155	288.7	1.10	13.25	58300
Rathdrum	Coeur d'Alene	Fourth St. Well	19870804	194.5	212.0	17.5	3238	185.0	1.60	19.25	347000
Rathdrum	Coeur d'Alene	Linden St. Well	19870804	169.0	178.0	9.0	2604	289.3	1.27	15.25	574000
Rathdrum	Coeur d'Alene	Atlas Road Well		241.0	245.0	4.0	1155	288.8	1.10	13.25	583000
Rathdrum	Coeur d'Alene	Locust St. Well	19870804	174.0	175.8	1.8	1655	919.7	1.10	13.25	1960000

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(Uses confined aquifer storage coefficient)

Idaho Wellhead Protection Plan

2.5.5 Hydraulic Conductivities by Rock Type

Table 2-15. Hydraulic Conductivity Values—Eastern Snake River Plain (feet/second (Garabedian, 1989).

Hydraulic Conductivity Values - Eastern Snake River Plain (From Table 19, Garabedian 1989)					
	Basalt	Sand and gravel	Sand	Clay and Silt	Silicic Volcanics (rhyolite)
Zone No.	(x 10^{-4})	(x 10^{-4})	(x 10^{-4})	(x 10^{-6})	(x 10^{-6})
feet/second					
1	0.052	11	0.11	2.3	7.5
2	5.5	90	0.90	0.75	7.5
3	550	73	0.73	2.3	7.5
4	0.9	17	0.17	0.75	7.5
5	803	110	1.1	2.3	7.5
6	2.4	47	0.63	2.3	7.5
7	2.1	41	0.41	2.3	7.5
8	56	140	1.4	0.38	7.5
9	0.75	7.5	0.075	0.75	7.5
10	5.7	110	1.1	0.75	7.5
11	3.8	3.8	3.8	0.38	7.5
12	23	75	0.75	2.3	7.5
13	580	2,000	0.1	0.38	7.5
14	1,100	1,900	1.9	2.3	7.5
15	11	71	0.71	0.38	7.5
16	230	38	0.38	2.3	7.5
17	61	330	0.66	2.3	7.5
18	6	11	1.1	2.3	7.5
19	670	1,700	1.7	2.3	7.5
20	150	71	0.71	2.3	7.5
21	590	83	0.83	2.3	7.5
22	50	29	0.29	0.38	7.5
23	120	83	0.83	2.3	7.5
24	440	83	0.83	2.3	7.5
25	2.9	59	0.59	2.3	7.5
26	200	48	0.48	2.3	7.5
27	68	47	0.62	2.3	7.5
28	3	58	0.58	2.3	7.5
29	1.5	31	0.31	0.75	7.5
30	3.9	11	0.11	0.38	7.5
31	1.6	26	0.26	0.75	7.5
32	380	38	0.38	2.3	7.5
33	420	210	2.1	2.3	7.5
34	250	300	0.30	2.3	7.5
35	66	140	66	0.38	7.5
36	600	1,500	600	7.5	7.5
37	15	15	0.23	2.3	7.5
38	150	83	0.83	3.8	7.5
39	120	18	0.18	2.3	7.5

Table 2-16. Hydraulic Conductivity Values—Eastern Snake River Plain (feet/day) (from Garabedian, 1989).

Hydraulic Conductivity Values - Eastern Snake River Plain (From Table 19, Garabedian 1989)					
Zone No.	Basalt	Sand and gravel	Sand	Clay and Silt	Silicic Volcanics (rhyolite)
			feet/day		
1	0.45	95.0	0.95	0.20	0.65
2	47.5	778	7.78	0.06	0.65
3	4752	631	6.31	0.20	0.65
4	7.78	147	1.47	0.06	0.65
5	6938	950	9.50	0.20	0.65
6	20.7	406	5.44	0.20	0.65
7	18.1	354	3.54	0.20	0.65
8	484	1210	12.1	0.03	0.65
9	6.48	64.8	0.65	0.06	0.65
10	49.2	950	9.50	0.06	0.65
11	32.8	32.8	32.8	0.03	0.65
12	199	648	6.48	0.20	0.65
13	5011	17280	0.86	0.03	0.65
14	9504	16416	16.4	0.20	0.65
15	95.0	613	6.13	0.03	0.65
16	1987	328	3.28	0.20	0.65
17	527	2851	5.70	0.20	0.65
18	51.8	95.0	9.50	0.20	0.65
19	5789	14688	14.7	0.20	0.65
20	1296	613	6.13	0.20	0.65
21	5098	717	7.17	0.20	0.65
22	432	251	2.51	0.03	0.65
23	1037	717	7.17	0.20	0.65
24	3802	717	7.17	0.20	0.65
25	25.1	510	5.10	0.20	0.65
26	1728	415	4.15	0.20	0.65
27	588	406	5.36	0.20	0.65
28	25.9	501	5.01	0.20	0.65
29	13.0	268	2.68	0.06	0.65
30	33.7	95.0	0.95	0.03	0.65
31	13.82	225	2.25	0.06	0.65
32	3283	328	3.28	0.20	0.65
33	3629	1814	18.1	0.20	0.65
34	2160	2592	2.59	0.20	0.65
35	570	1210	570	0.03	0.65
36	5184	12960	5184	0.65	0.65
37	130	130	1.99	0.20	0.65
38	1296	717	7.17	0.33	0.65
39	1037	156	1.56	0.20	0.65
40	1728	2246	2.25	0.20	0.65

2.5.6 Hydraulic Conductivity Zones; East Snake River Plain

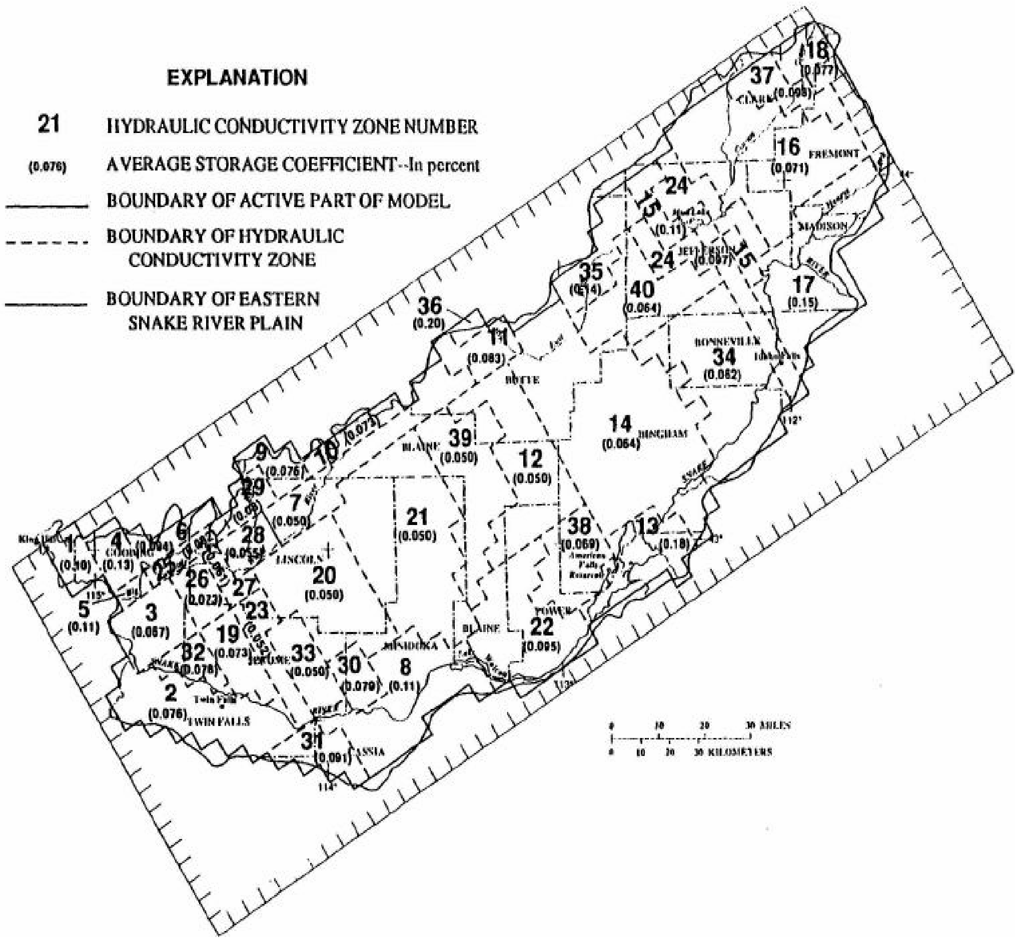

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Figure 2-11. Hydraulic Conductivity zones and average storage coefficients, model level 1 (Garabedian, 1989)

2.5.7 Hydraulic Conductivity and Permeability

Table 2.2 Range of Values of Hydraulic Conductivity and Permeability

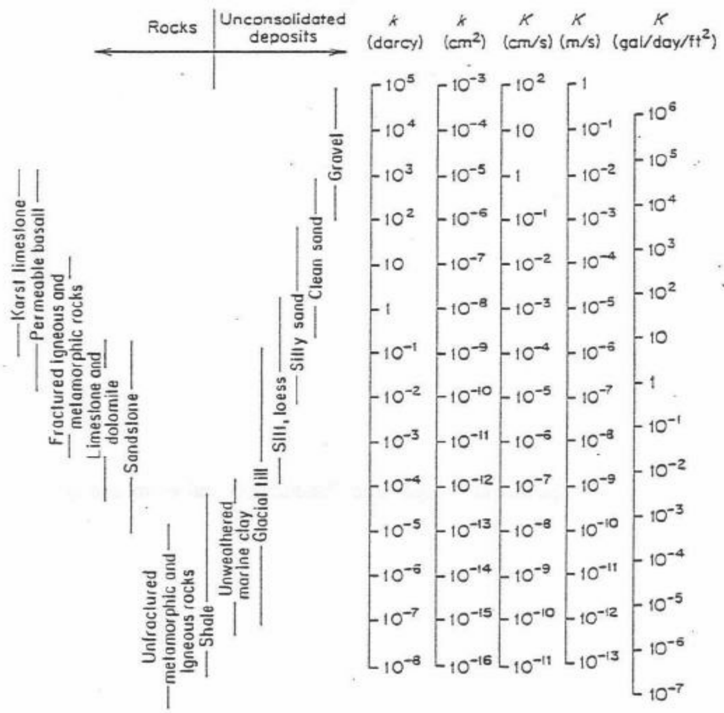

Table 2.3 Conversion Factors for Permeability and Hydraulic Conductivity Units

	Permeability, k*			Hydraulic conductivity, K		
	cm²	ft²	darcy	m/s	ft/s	gal/day/ft²
cm²	1	1.08×10^{-3}	1.01×10^{8}	9.80×10^{2}	3.22×10^{3}	1.85×10^{9}
ft²	9.29×10^{2}	1	9.42×10^{10}	9.11×10^{5}	2.99×10^{6}	1.71×10^{12}
darcy	9.87×10^{-9}	1.06×10^{-11}	1	9.66×10^{-6}	3.17×10^{-5}	1.82×10^{1}
m/s	1.02×10^{-3}	1.10×10^{-6}	1.04×10^{5}	1	3.28	2.12×10^{6}
ft/s	3.11×10^{-4}	3.35×10^{-7}	3.15×10^{4}	3.05×10^{-1}	1	5.74×10^{5}
gal/day/ft²	5.42×10^{-10}	5.83×10^{-13}	5.49×10^{-2}	4.72×10^{-7}	1.74×10^{-6}	1

*To obtain k in ft², multiply k in cm² by 1.08×10^{-3}.

Freeze and Cherry, 1979, Groundwater - Chapter 2, page 29, Tables 2.2 and 2.3

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Figure 2-12. Hydraulic Conductivity and Permeability (Freeze and Cherry, 1979)

2.5.8 Hydraulic Conductivity Values, Treasure Valley Idaho (DEQ, 2005)

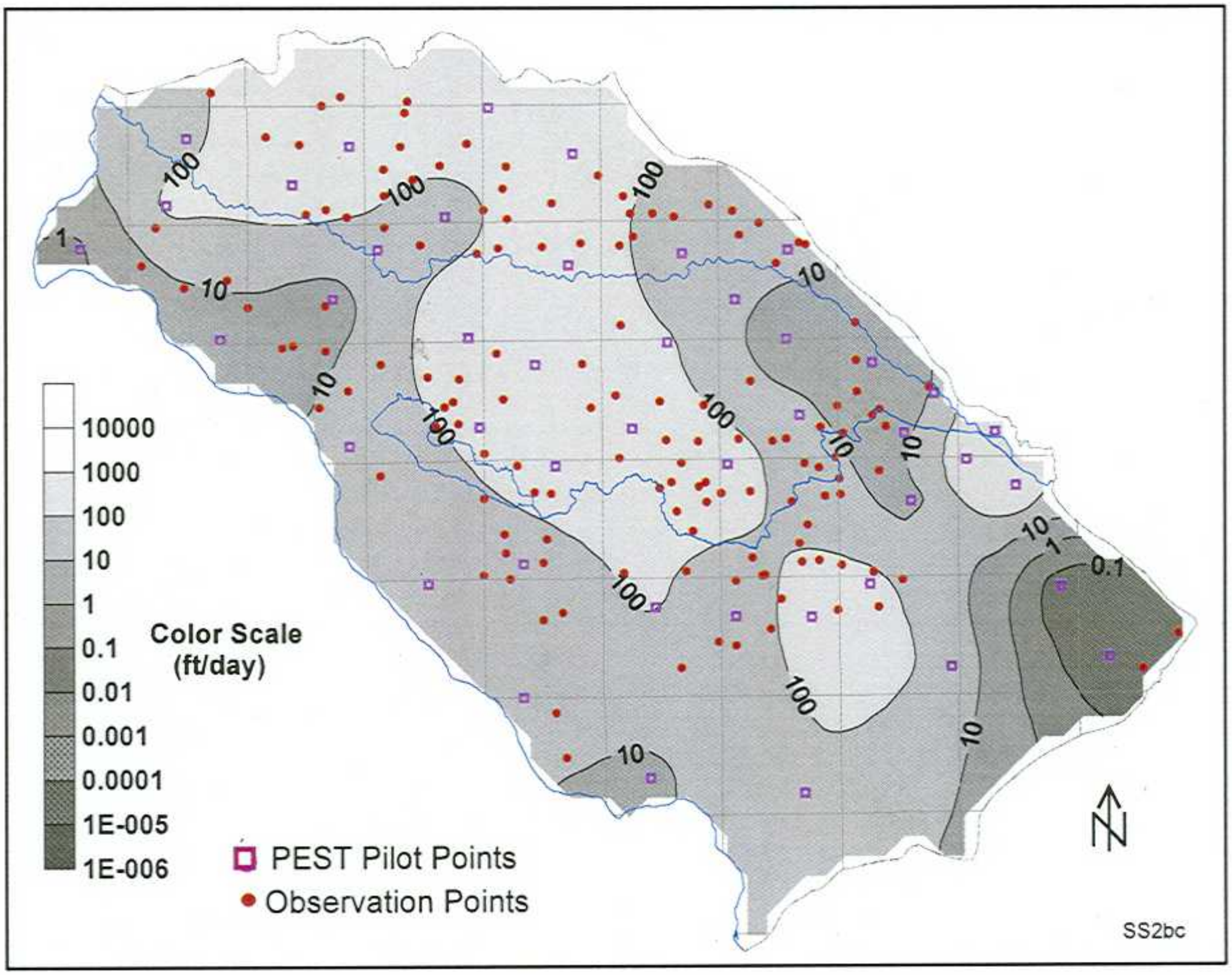

Figure 2-13. Layer 1 Horizontal Hydraulic Conductivity Value Distributions from Treasure Valley Hydrologic Model (IWRRI, 2004b).

Treasure Valley Hydraulic Conductivity Zones for the Uppermost Aquifer

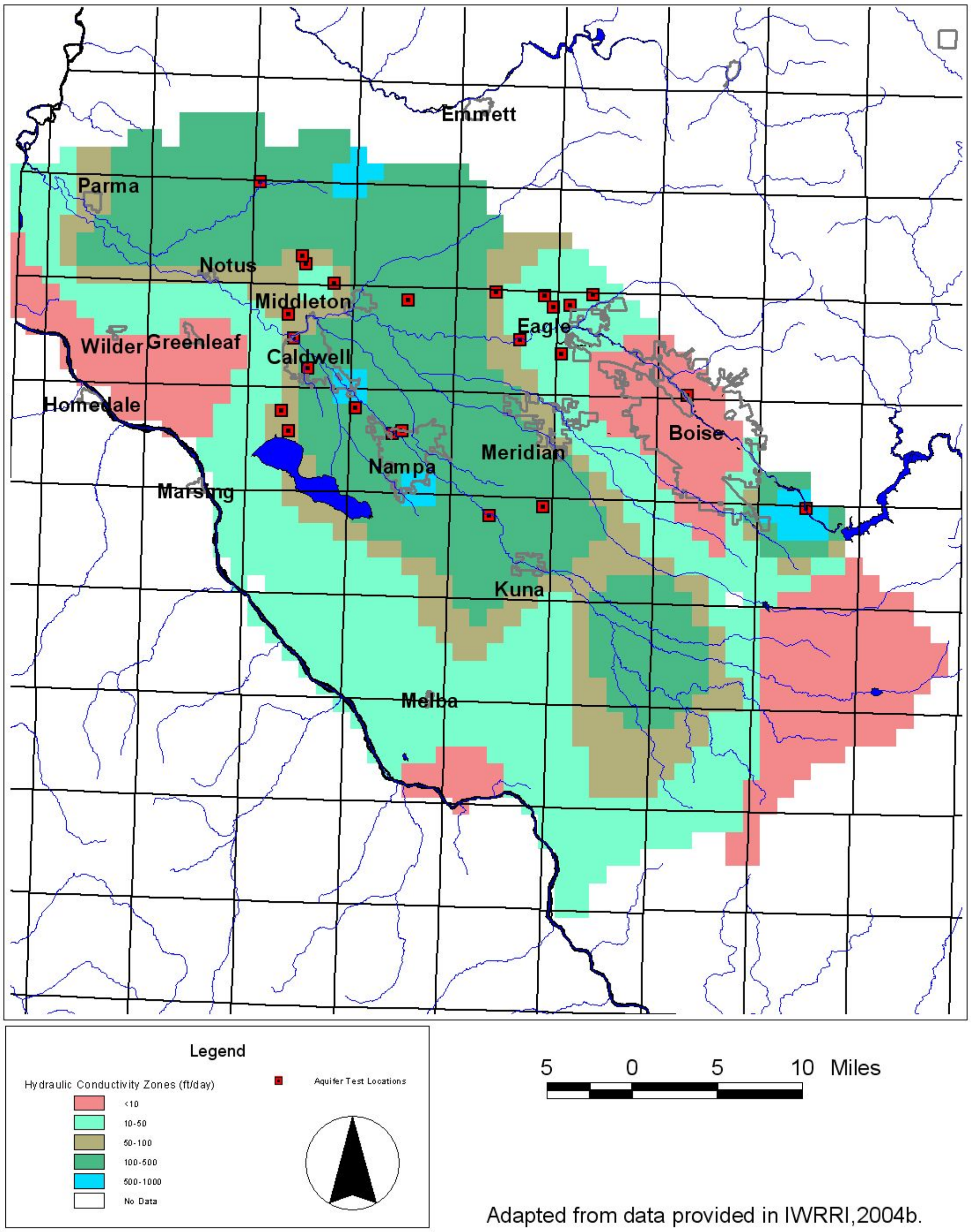

Figure 2-14. Hydraulic Conductivity Zones Adapted from Treasure Valley Hydrologic Model Steady State Layer 1 Horizontal Hydraulic Conductivity Values (feet/day).

2.5.9 Ranges in Porosity Values for Geological Materials

Table 2-17. Ranges of Porosity Values for Geological Materials

	Domenico and Schwartz, 1998		**Freeze and Cherry, 1979**		**Driscoll, 1987**
Material	Porosity (%)	Material	Porosity (%)	Material	Porosity (%)
Sedimentary					
Gravel, coarse	24 – 36	Gravel	25 – 40	Gravel	25 - 40
Gravel, fine	25 – 38			Sand and Gravel mixes	10 – 35
Sand, coarse	31 – 46			Glacial till	10 – 25
Sand, fine	26 – 53	Sand	25 – 50	Sand	25 – 40
Silt	34 – 61	Silt	35 – 50	Silt	35 – 55
Clay	34 – 60	Clay	40 – 70	Clay	45 – 55
Sedimentary Rocks					
Sandstone	5 – 30	Sandstone	5 – 30	Sandstone	5 - 30
Siltstone	21 – 41				
Limestone, dolomite	0 – 20	Limestone, dolomite	0 – 20	Limestone/dolomite (original and secondary porosity)	1 – 20
Karst limestone	5 – 50	Karst Limestone	5 – 50		
Shale	0 – 10	Shale	0 – 10	Shale	0 – 10
Crystalline Rocks					
Fractured crystalline rocks	0 – 10	Fractured crystalline rocks	0 – 10	Fractured crystalline rock	0 - 10
Dense crystalline rocks	0 – 5	Dense crystalline rocks	0 – 5	Dense, solid rock	<1
Basalt	3 – 35	Fractured Basalt	5 – 50	Vesicular Basalt	10 – 50
Weathered granite	34 – 57				
Weathered gabbro	42 – 45				

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